

# **Exhibit B**

**Table of Intrinsic Evidence Exhibits**

<b>Exhibit No.</b>	<b>Document Description</b>
1.	U.S. Patent No. D883,279
2.	U.S. Patent No. D947,842
3.	U.S. Patent No. D962,936
4.	U.S. Patent No. D735,131
5.	U.S. Patent No. 10,076,257
6.	U.S. Patent No. 10,627,783
7.	U.S. Patent No. 10,942,491
8.	U.S. Patent No. 10,987,054
9.	U.S. Patent No. 11,106,352
10.	U.S. Patent No. 11,474,483
11.	U.S. Patent Application Publication No. 2016/0202865
12.	Response to Office Action dated 01/15/2018 as excerpted from U.S. Patent No. 10,076,257 File History
13.	Response to Office Action dated 09/02/2016 as excerpted from U.S. Patent No. 10,076,257 File History
14.	Office Action dated 05/13/2020 as excerpted from U.S. Patent No. 10,942,491 File History
15.	IPR2023-00634, Paper 1 - Petition for <i>Inter Partes</i> Review of U.S. Patent No. 10,627,783
16.	IPR2023-00664, Paper 1 - Petition for <i>Inter Partes</i> Review of U.S. Patent No. 11,106,352
17.	IPR2023-00734, Paper 1 - Petition for <i>Inter Partes</i> Review of U.S. Patent No. 10,942,491
18.	IPR2023-00745, Paper 1 - Petition for <i>Inter Partes</i> Review of U.S. Patent No. 10,076,257
19.	IPR2023-00807, Paper 1 - Petition for <i>Inter Partes</i> Review of U.S. Patent No. 11,474,483

# EXHIBIT 1



US00D883279S

(12) **United States Design Patent** (10) **Patent No.:** **US D883,279 S**  
**Akana et al.** (45) **Date of Patent:** **\*\* May 5, 2020**

(54) **ELECTRONIC DEVICE**(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

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(73) Assignee: **Apple Inc.**, Cupertino, CA (US)(\*\*) Term: **15 Years**(21) Appl. No.: **29/684,822**(22) Filed: **Mar. 25, 2019****Related U.S. Application Data**

(63) Continuation of application No. 29/654,754, filed on Jun. 27, 2018.

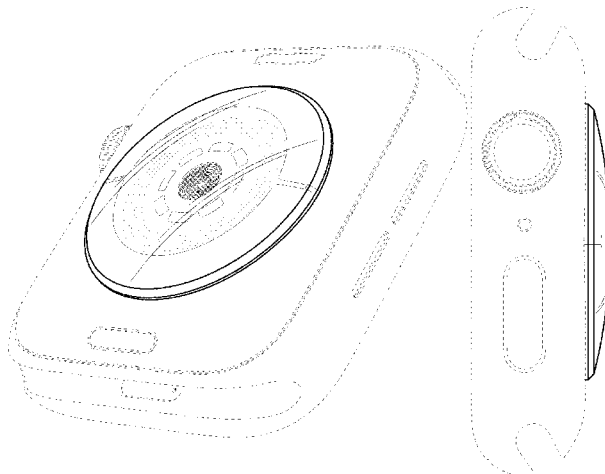
(51) **LOC (12) Cl.** ..... **14-02**(52) **U.S. Cl.**USPC ..... **D14/344**(58) **Field of Classification Search**

USPC ... D14/138 R, 144, 341, 344, 358, 388, 218,  
D14/485-495; D10/30-39, 70, 98;  
D11/3, 4, 26, 93-94, 78.1, 79, 86;  
D24/167, 169, 186-187, 164  
CPC ..... A41D 1/002; A41D 19/0034; G06F 1/04;  
G06F 1/08; G06F 1/10; G06F 1/14; G06F  
1/1626; G06F 1/1628; G06F 1/163; G06F  
1/1635; G06F 1/3203; G06Q 20/10;  
G06Q 20/12; G06Q 20/108; G06Q  
20/145; H04B 1/3833; H04B 1/385;  
H04B 1/3888; H04M 1/02; H04M 1/03;  
H04M 1/04; H04M 1/05; H04M 1/667;  
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See application file for complete search history.

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(57)

## CLAIM

The ornamental design for an electronic device, as shown and described.

## DESCRIPTION

FIG. 1 is a bottom front perspective view of an electronic device showing the claimed design;

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FIG. 2 is a bottom rear perspective view thereof;  
FIG. 3 is a front view thereof;  
FIG. 4 is a rear view thereof;  
FIG. 5 is a left side view thereof;  
FIG. 6 is a right side view thereof;  
FIG. 7 is a top view thereof;  
FIG. 8 is a bottom view thereof; and,  
FIG. 9 is a bottom front perspective reference view thereof showing the electronic device in an environment in which it may be used.  
The broken lines in the figures show portions of the electronic device and environment that form no part of the claimed design.

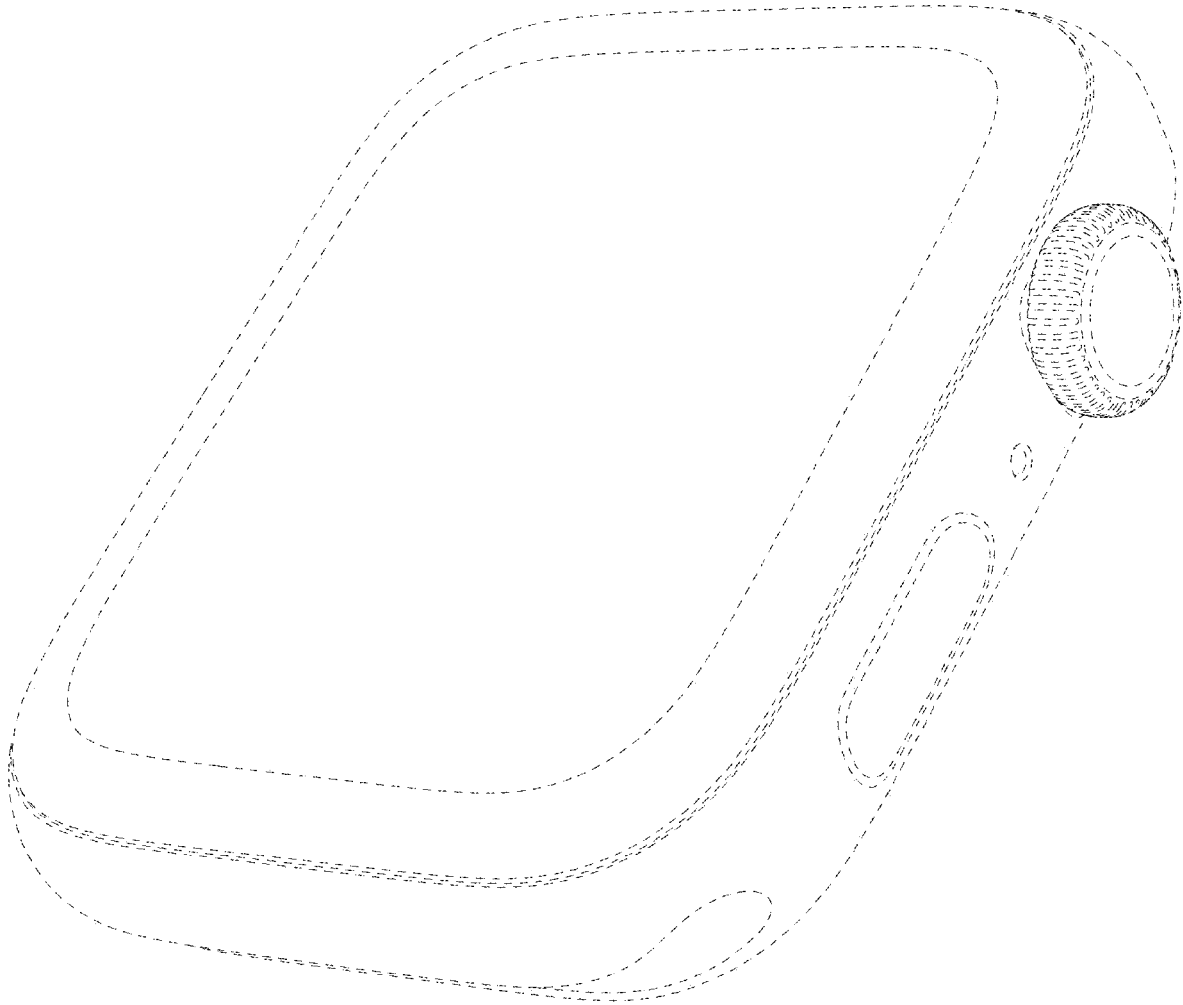
**1 Claim, 7 Drawing Sheets**

**U.S. Patent**

**May 5, 2020**

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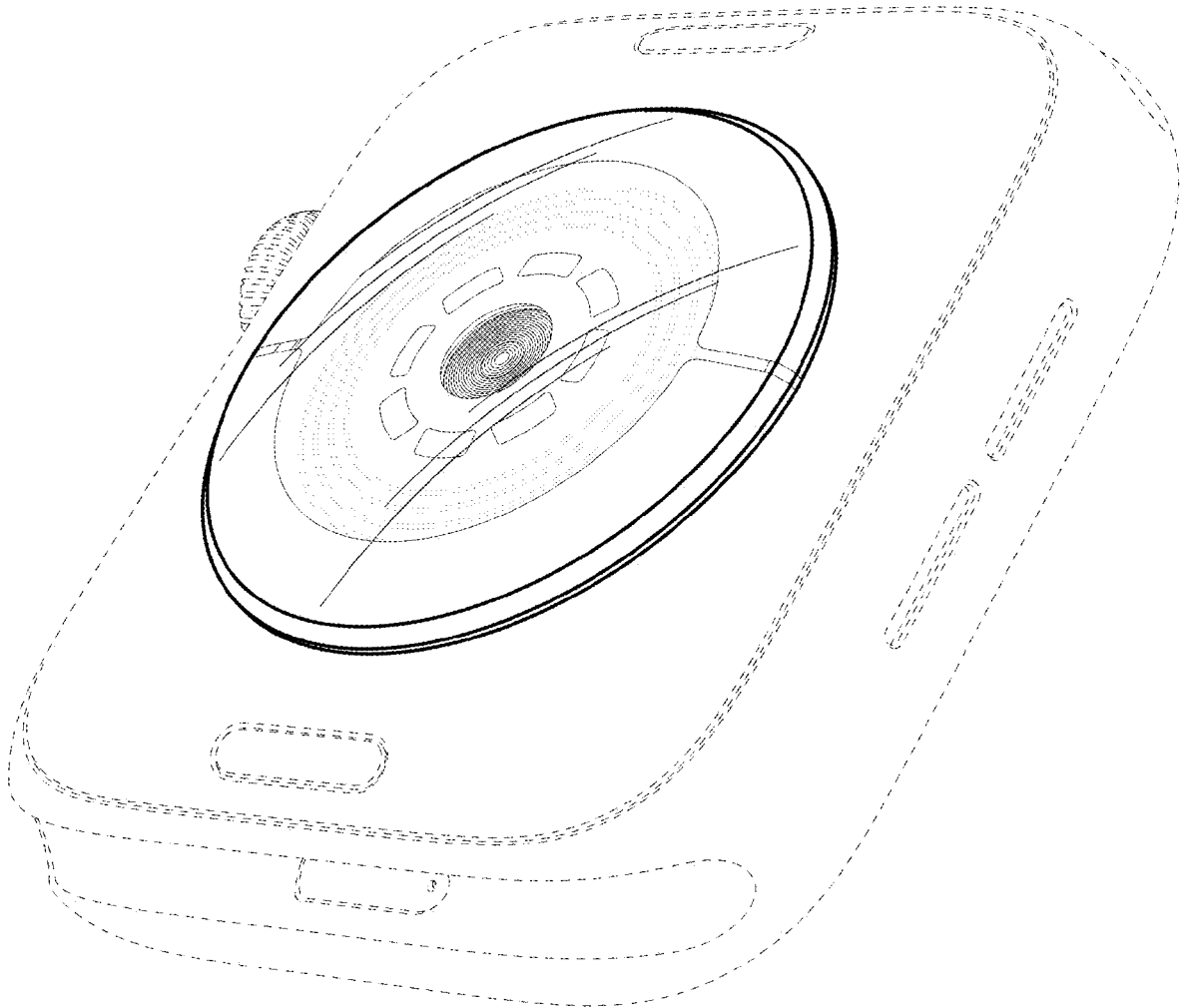
**FIG. 1**

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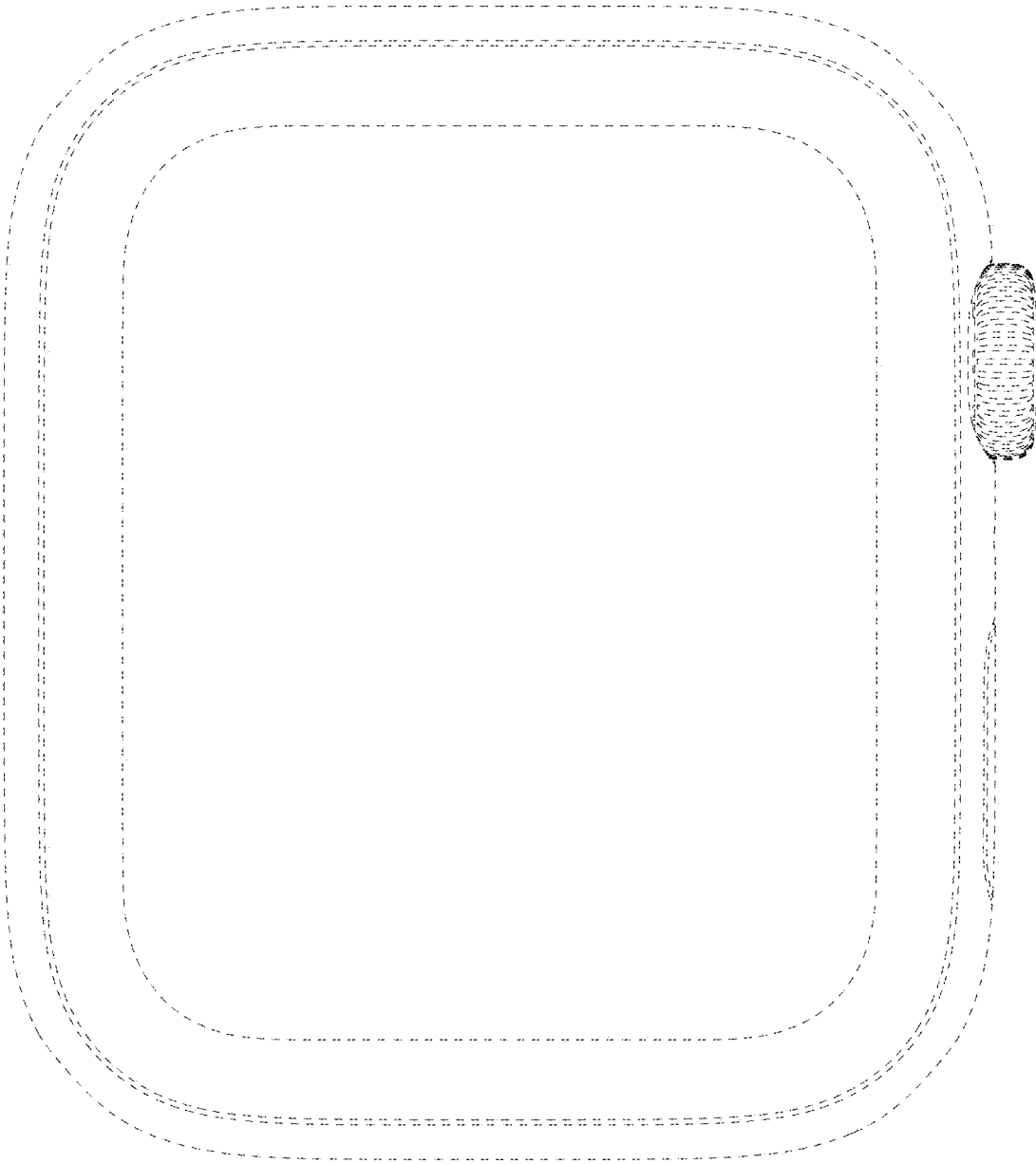
**FIG. 2**

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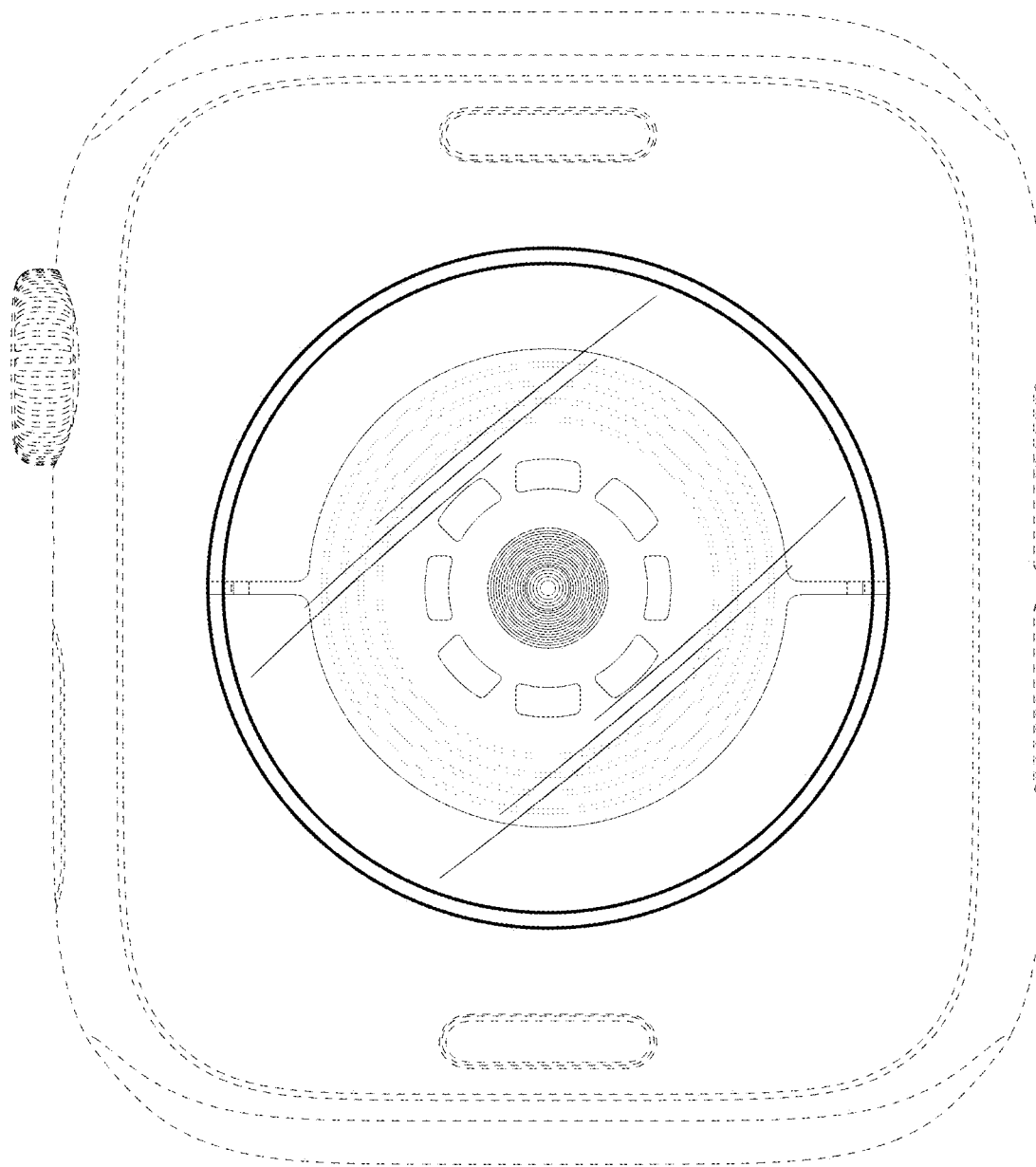
**FIG. 3**

**U.S. Patent**

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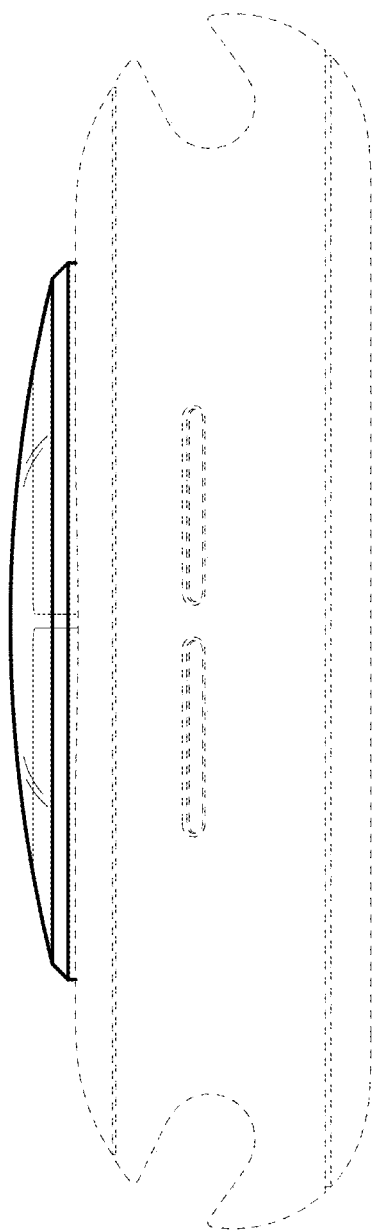
**FIG. 4**

**U.S. Patent**

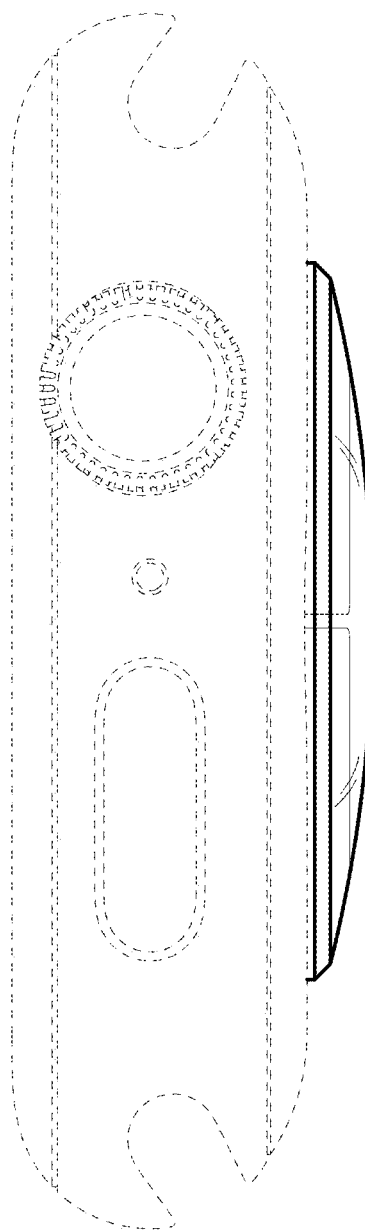
**May 5, 2020**

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**FIG. 5**



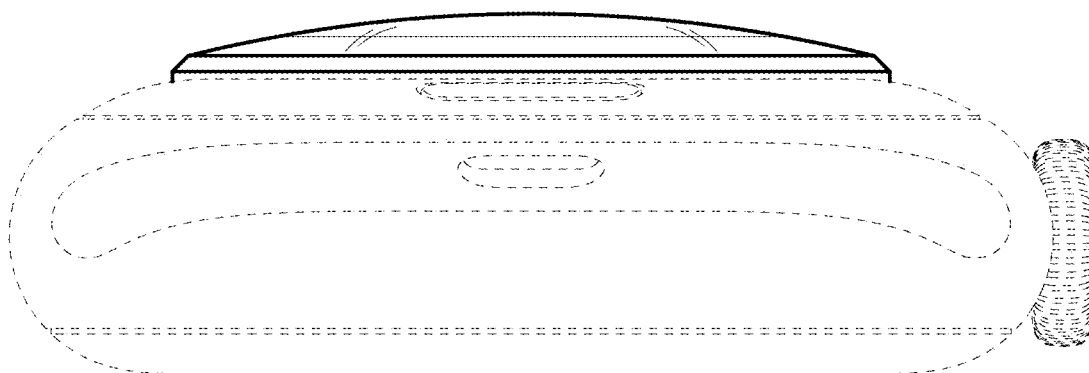
**FIG. 6**

**U.S. Patent**

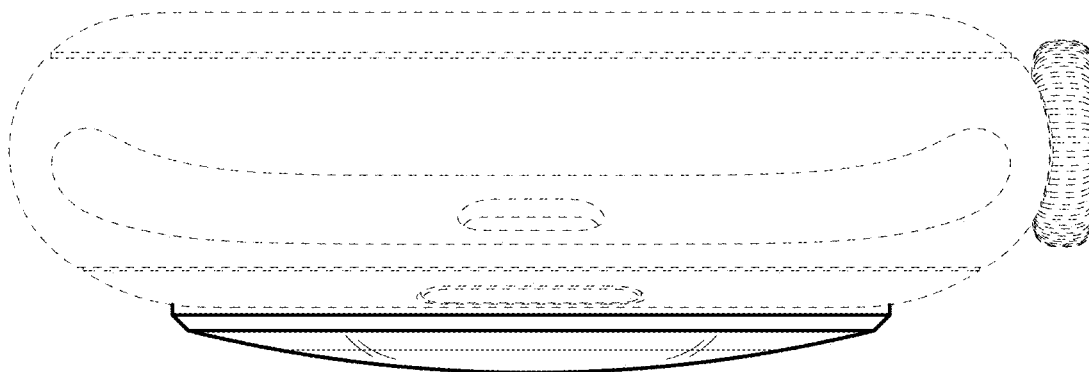
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**FIG. 7**



**FIG. 8**

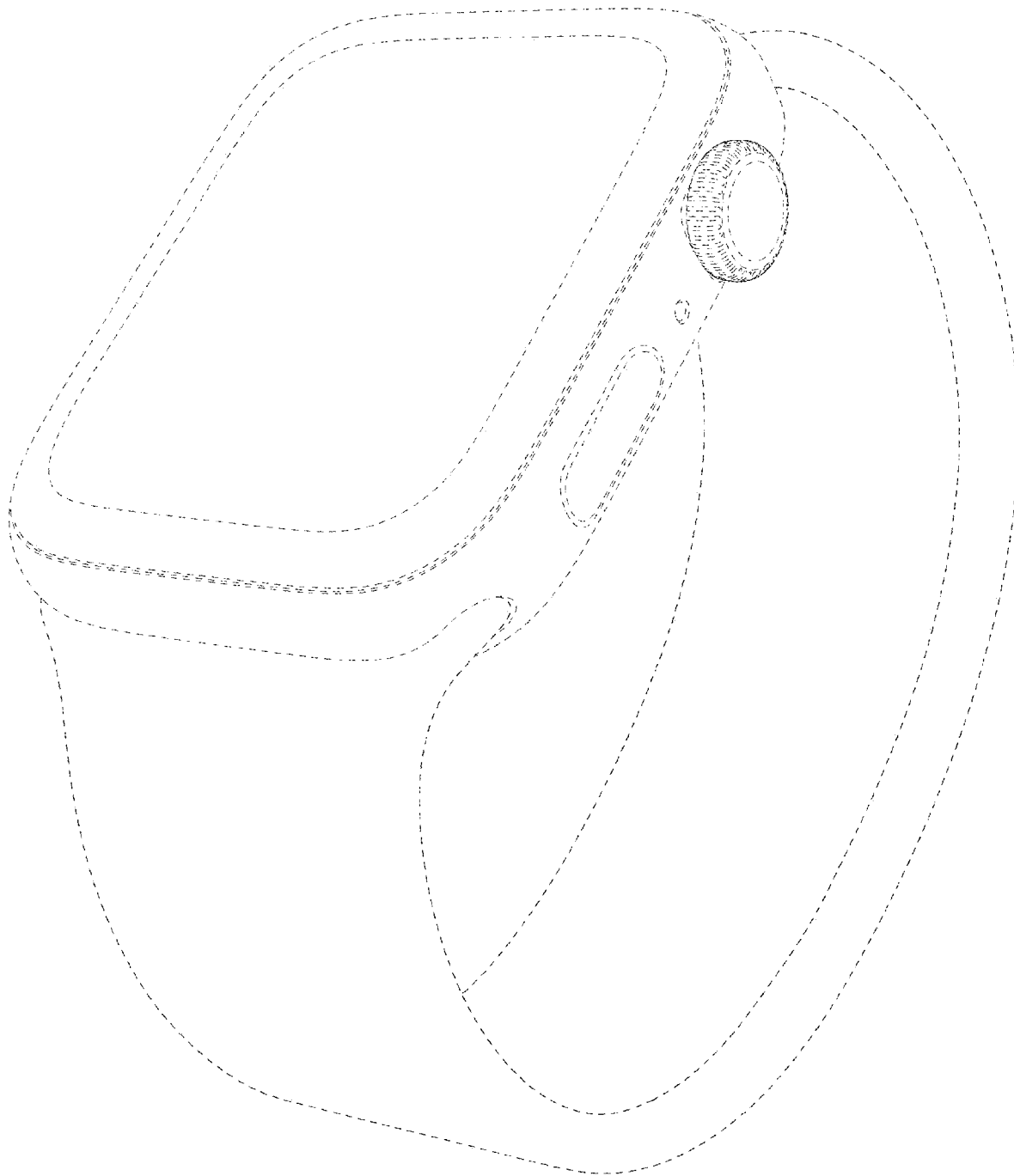


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**Sheet 7 of 7**

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**FIG. 9**

# **EXHIBIT 2**



US00D947842S

(12) **United States Design Patent** (10) **Patent No.:** **US D947,842 S**  
**Akana et al.** (45) **Date of Patent:** **\*\* Apr. 5, 2022**

(54) **ELECTRONIC DEVICE**(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

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(US); **Shota Aoyagi**, San Francisco, CA  
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**Jonathan P. Ive**, San Francisco, CA  
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**Whang**, San Francisco, CA (US); **Rico**  
**Zörkendörfer**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)(\*\*) Term: **15 Years**(21) Appl. No.: **29/816,024**(22) Filed: **Nov. 18, 2021****Related U.S. Application Data**

(63) Continuation of application No. 29/780,292, filed on  
Apr. 23, 2021, which is a continuation of application  
(Continued)

(51) **LOC (13) Cl.** ..... **14-02**(52) **U.S. Cl.**USPC ..... **D14/344**(58) **Field of Classification Search**

USPC ..... D10/30, 31, 32, 38, 39; D14/138 R,  
D14/138 G, 144, 341, 344, 346, 388, 389,  
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*Primary Examiner* — Joseph Kukella

(74) *Attorney, Agent, or Firm* — Sterne, Kessler,  
Goldstein & Fox P.L.L.C.

(57) **CLAIM**

The ornamental design for an electronic device, as shown  
and described.

**DESCRIPTION**

FIG. 1 is a bottom front perspective view of an electronic  
device showing the claimed design;

FIG. 2 is a bottom rear perspective view thereof;

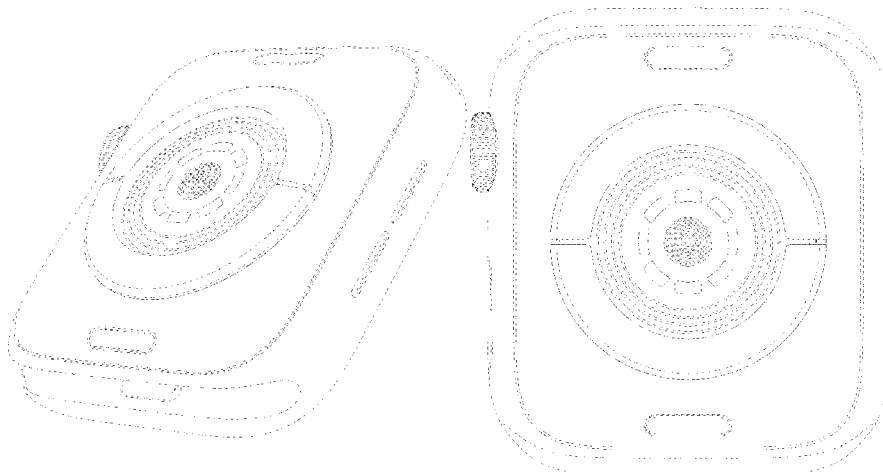
FIG. 3 is a front view thereof;

FIG. 4 is a rear view thereof;

FIG. 5 is a left side view thereof;

FIG. 6 is a right side view thereof;

(Continued)



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FIG. 7 is a top view thereof;  
 FIG. 8 is a bottom view thereof; and,  
 FIG. 9 is a bottom front perspective view thereof showing the electronic device in an environment in which it may be used.  
 The broken lines in the figures show portions of the electronic device and environment that form no part of the claimed design.

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### 1 Claim, 7 Drawing Sheets

### Related U.S. Application Data

No. 29/684,825, filed on Mar. 25, 2019, now Pat. No. Des. 917,470, which is a continuation of application No. 29/654,754, filed on Jun. 27, 2018, now Pat. No. Des. 882,563.

### (58) Field of Classification Search

CPC ..... G04G 17/00; G04G 17/045; G04G 17/08;  
 G04G 17/083; G04G 21/00; G04G 21/08;  
 G04G 99/006

See application file for complete search history.

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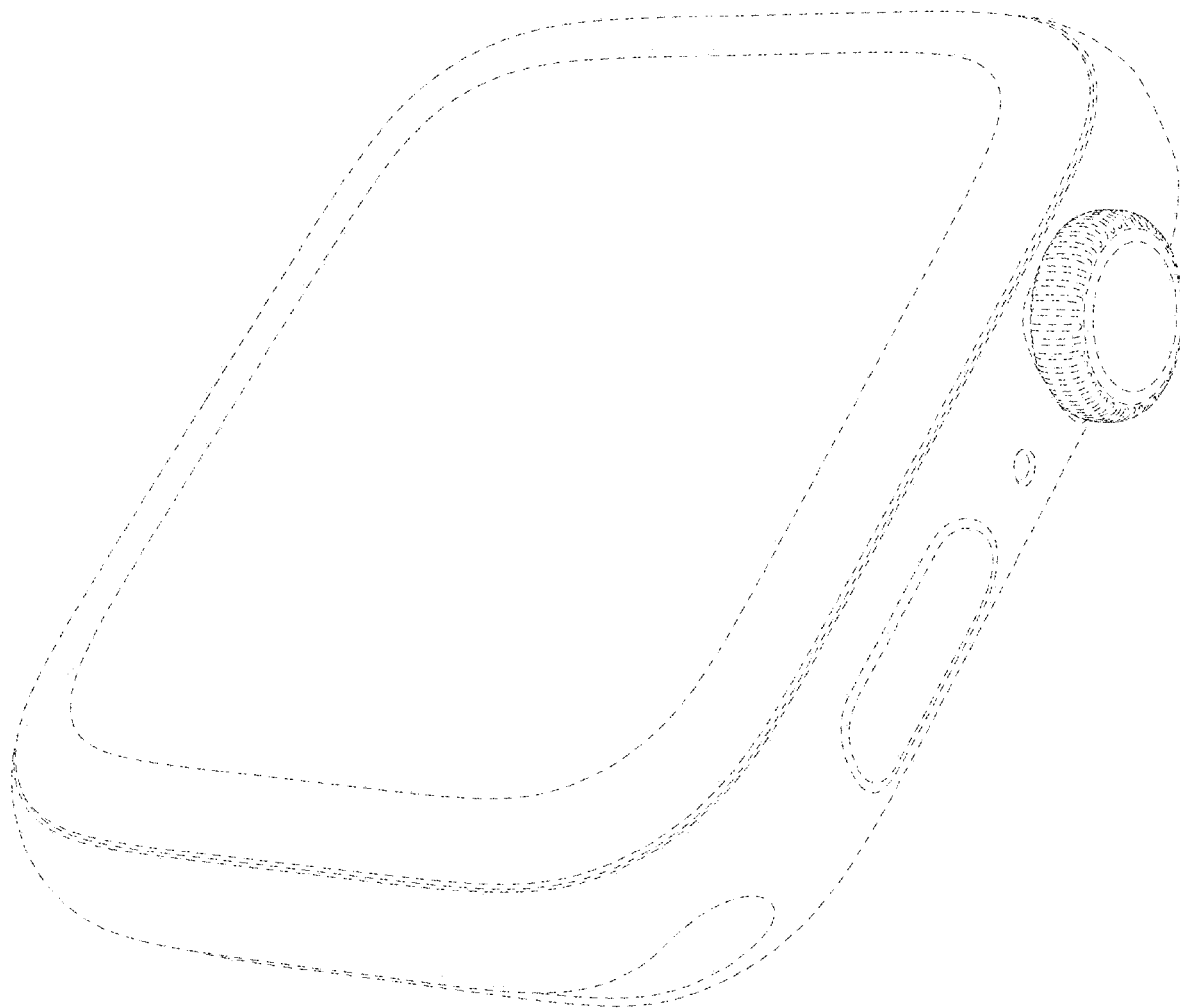
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**U.S. Patent**

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**Sheet 1 of 7**

**US D947,842 S**



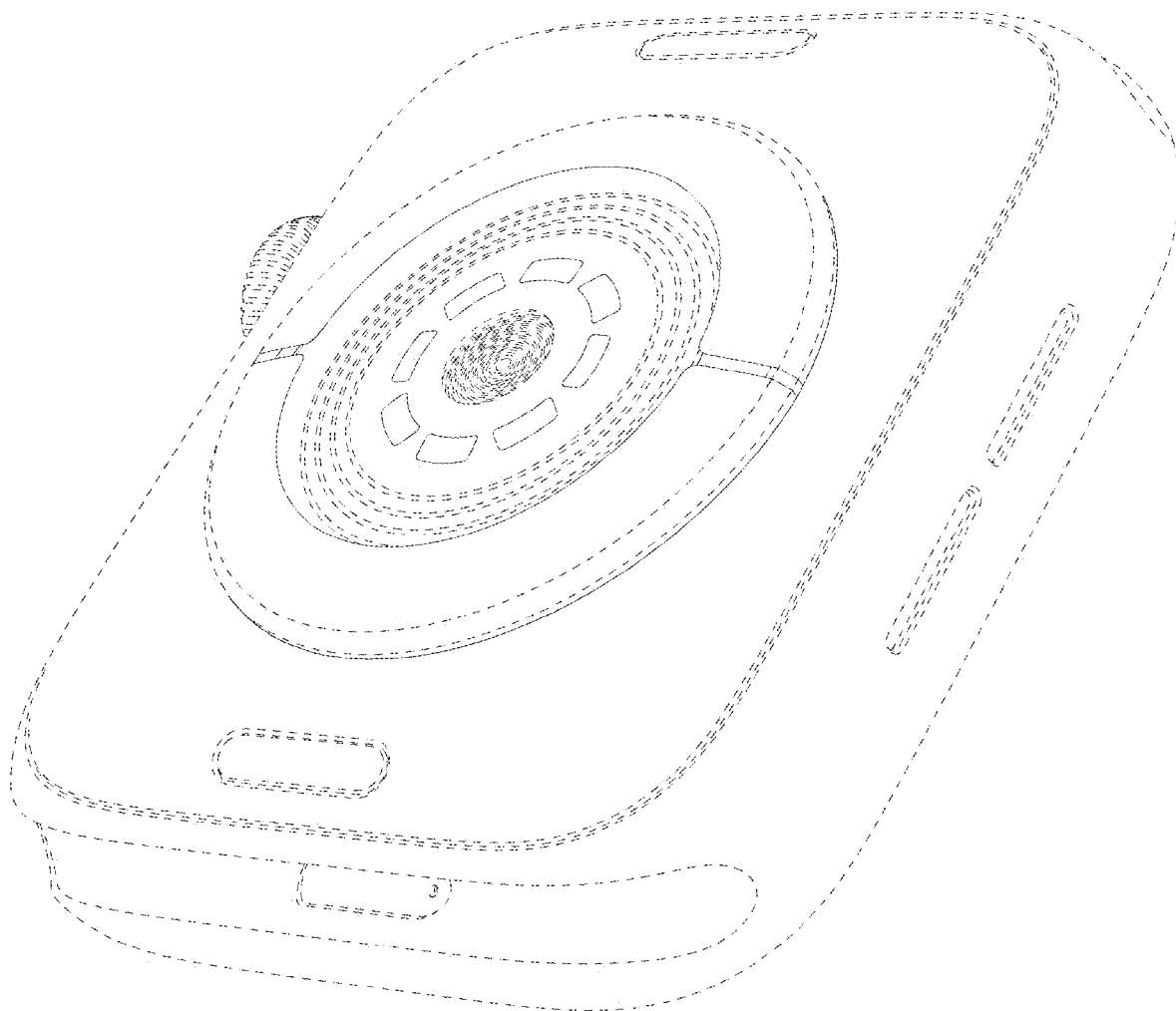
**FIG. 1**

**U.S. Patent**

**Apr. 5, 2022**

**Sheet 2 of 7**

**US D947,842 S**



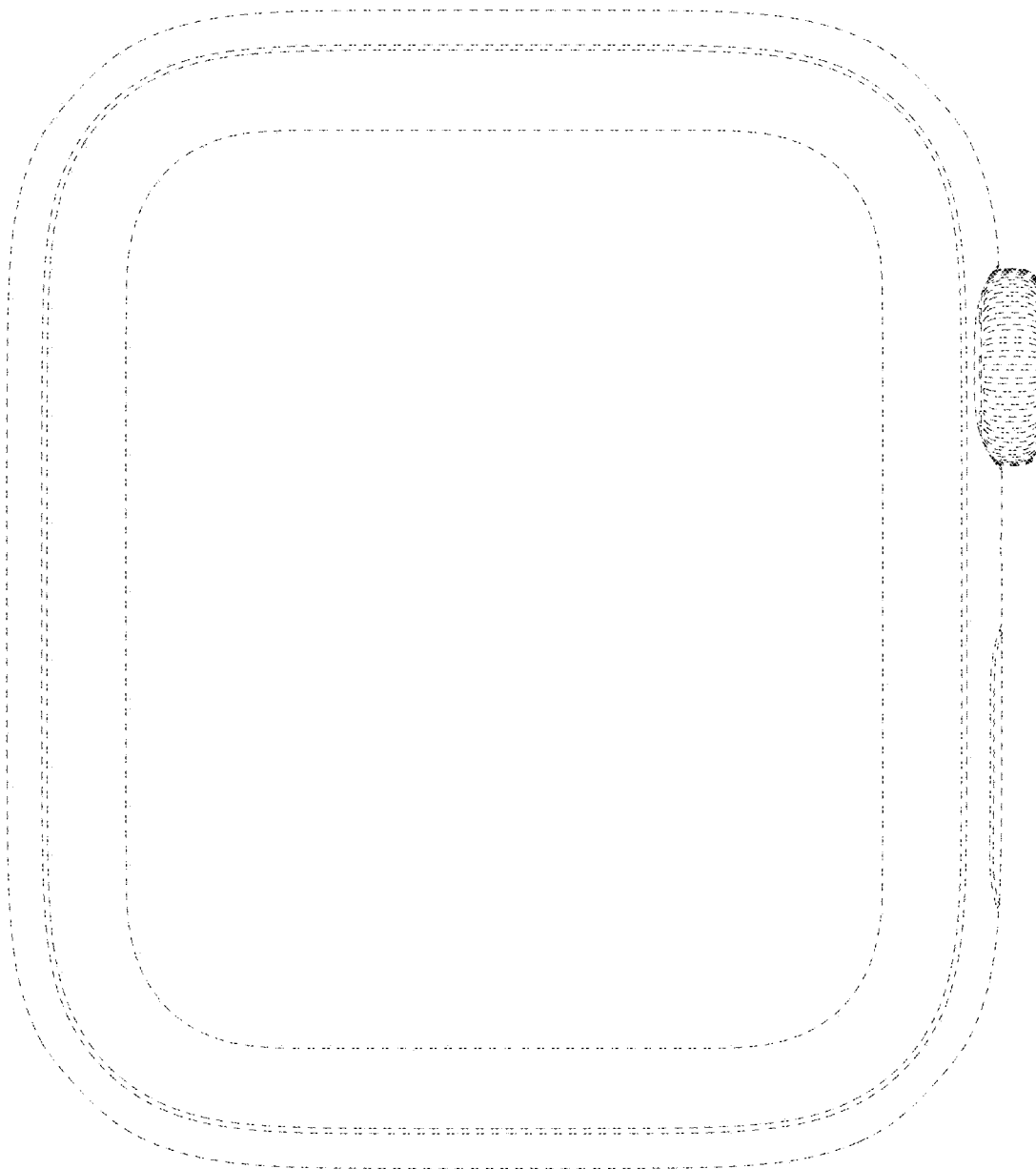
**FIG. 2**

**U.S. Patent**

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**US D947,842 S**



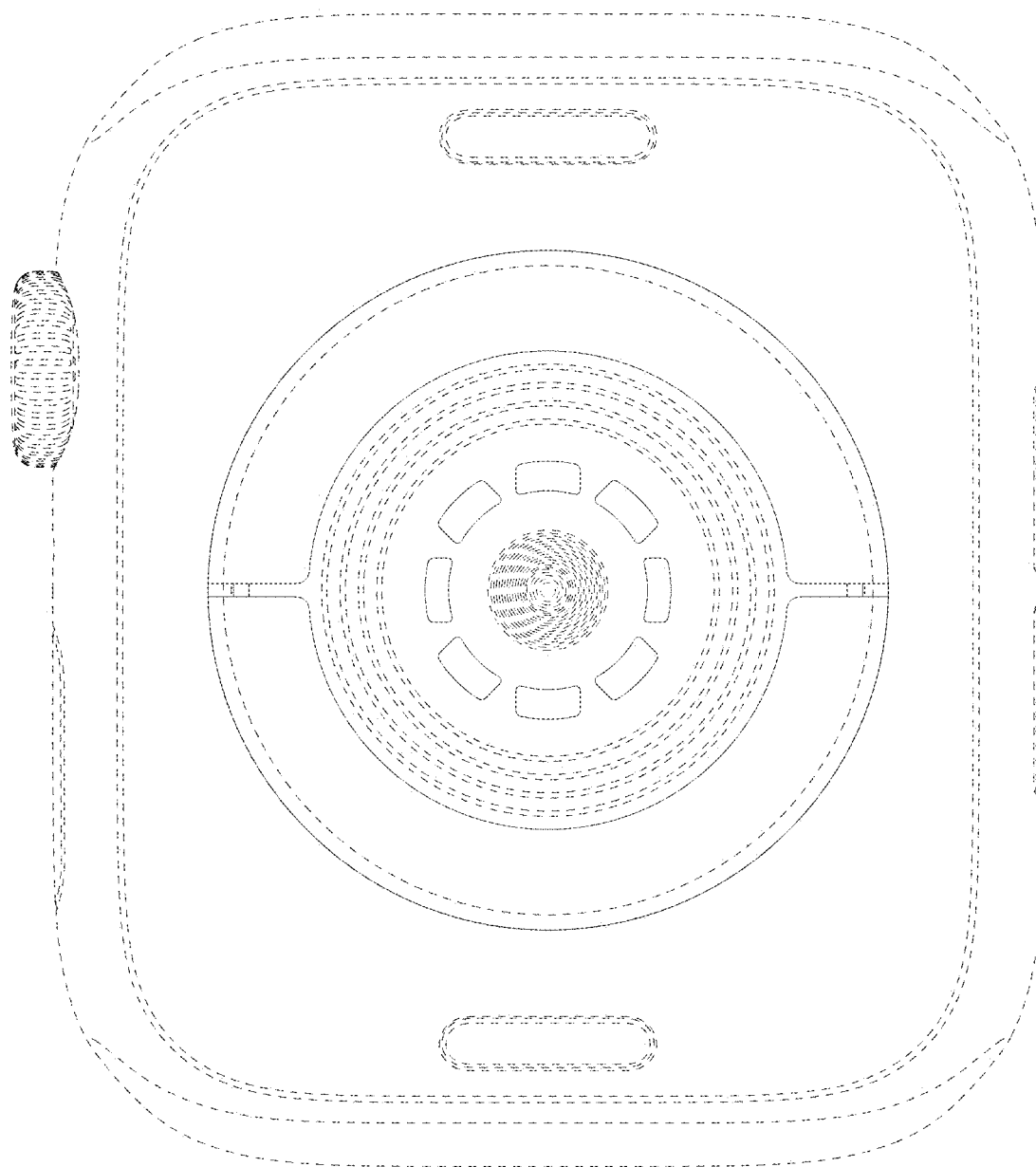
**FIG. 3**

**U.S. Patent**

**Apr. 5, 2022**

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**US D947,842 S**



**FIG. 4**

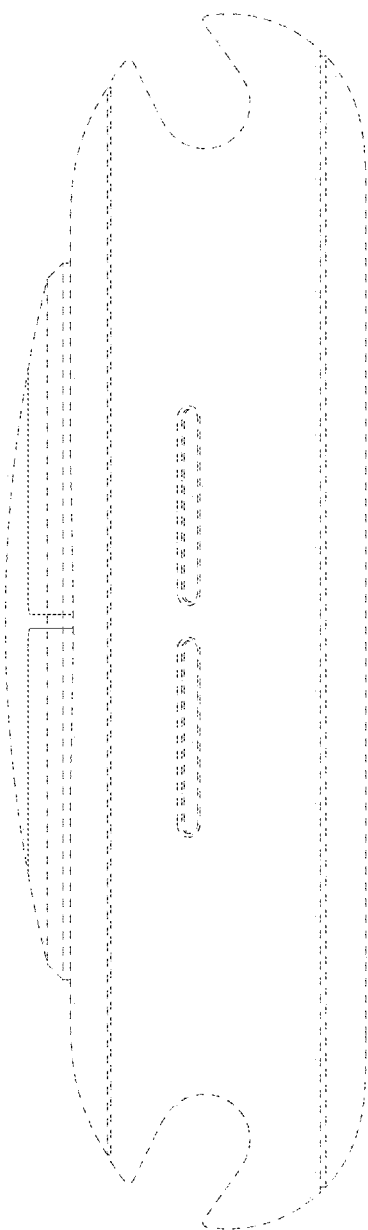


**U.S. Patent**

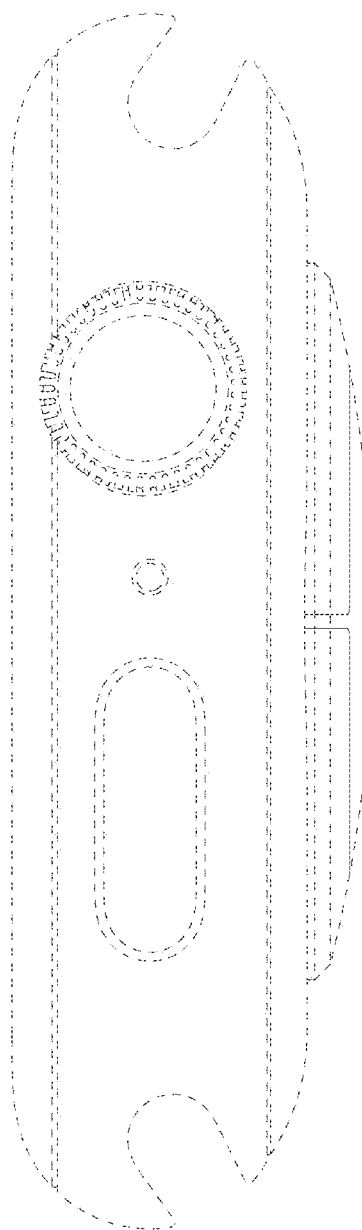
**Apr. 5, 2022**

**Sheet 5 of 7**

**US D947,842 S**



**FIG. 5**



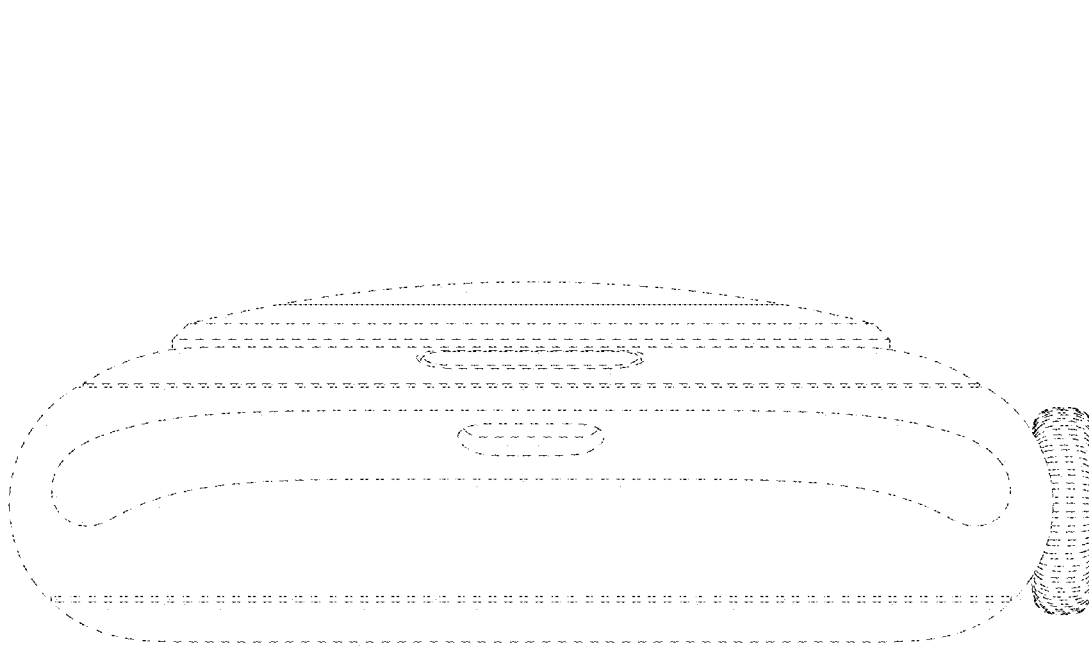
**FIG. 6**

**U.S. Patent**

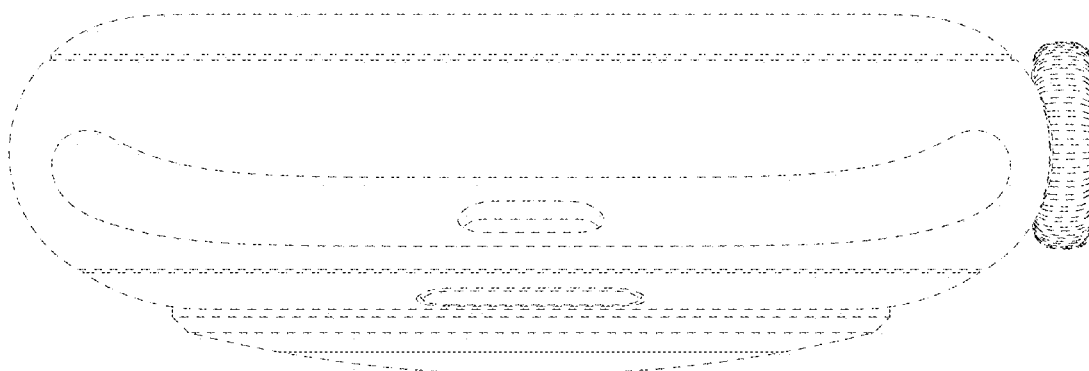
**Apr. 5, 2022**

**Sheet 6 of 7**

**US D947,842 S**



**FIG. 7**



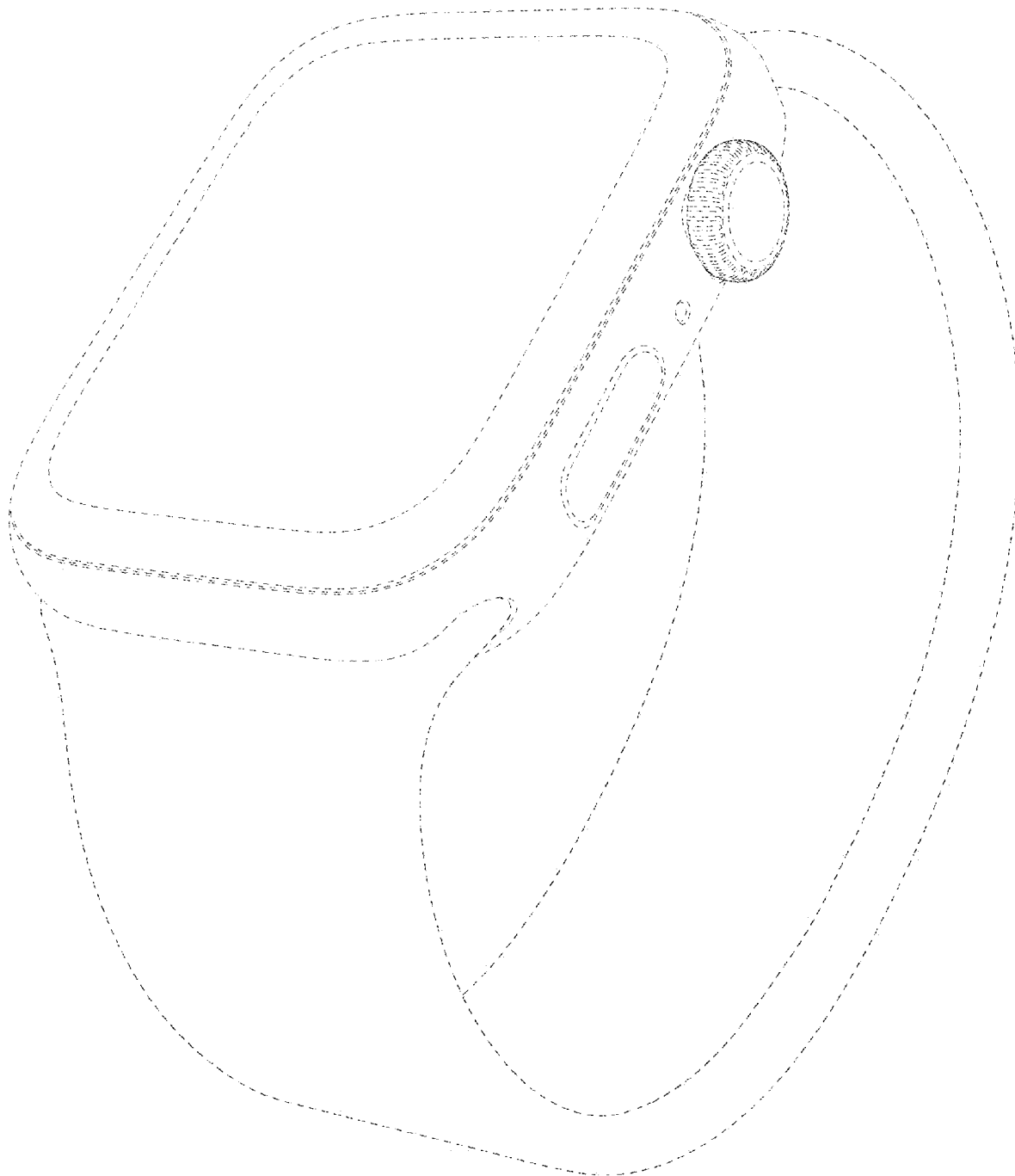
**FIG. 8**

**U.S. Patent**

**Apr. 5, 2022**

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**US D947,842 S**



**FIG. 9**

# **EXHIBIT 3**



US00D962936S

(12) **United States Design Patent** (10) **Patent No.:** **US D962,936 S**  
**Akana et al.** (45) **Date of Patent:** **\*\* Sep. 6, 2022**

(54) **ELECTRONIC DEVICE**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

(72) Inventors: **Jody Akana**, San Francisco, CA (US); **Molly Anderson**, San Francisco, CA (US); **Bartley K. Andre**, Palo Alto, CA (US); **Shota Aoyagi**, San Francisco, CA (US); **Anthony Michael Ashcroft**, San Francisco, CA (US); **Marine C. Bataille**, San Francisco, CA (US); **Jeremy Bataillou**, San Francisco, CA (US); **Markus Diebel**, San Francisco, CA (US); **M. Evans Hankey**, San Francisco, CA (US); **Julian Hoenig**, San Francisco, CA (US); **Richard P. Howarth**, San Francisco, CA (US); **Jonathan P. Ive**, San Francisco, CA (US); **Julian Jaede**, San Francisco, CA (US); **Duncan Robert Kerr**, San Francisco, CA (US); **Peter Russell-Clarke**, San Francisco, CA (US); **Benjamin Andrew Shaffer**, San Jose, CA (US); **Mikael Silvano**, San Francisco, CA (US); **Sung-Ho Tan**, Vienna (AT); **Clement Tissandier**, San Francisco, CA (US); **Eugene Antony Whang**, San Francisco, CA (US); **Rico Zörkendörfer**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(\*\*) Term: **15 Years**

(21) Appl. No.: **29/816,025**

(22) Filed: **Nov. 18, 2021**

#### Related U.S. Application Data

(63) Continuation of application No. 29/780,292, filed on Apr. 23, 2021, now Pat. No. Des. 949,146, which is (Continued)

(51) **LOC (13) Cl.** ..... **14-02**

(52) **U.S. Cl.**  
 USPC ..... **D14/344**

(58) **Field of Classification Search**  
 USPC ..... D10/30, 31, 32, 38, 39; D14/138 R,  
 D14/138 G, 144, 341, 344, 346, 388, 389,  
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*Primary Examiner* — Joseph Kukella

(74) *Attorney, Agent, or Firm* — Sterne, Kessler, Goldstein & Fox P.L.L.C.

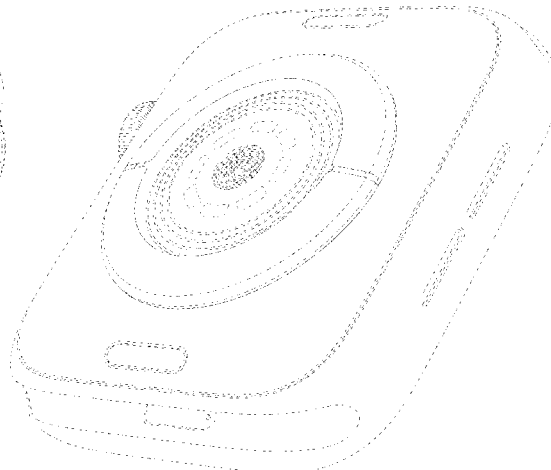
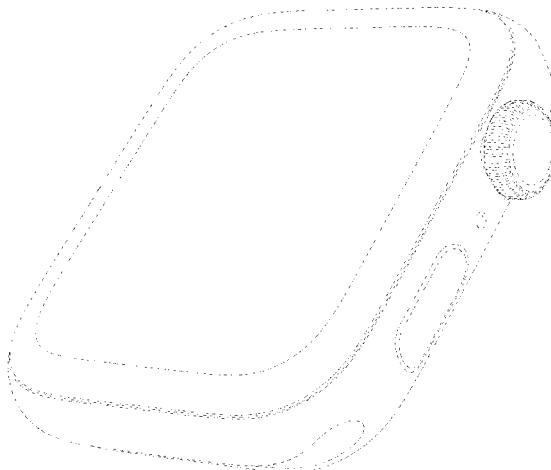
(57) **CLAIM**

The ornamental design for an electronic device, as shown and described.

#### DESCRIPTION

FIG. 1 is a bottom front perspective view of an electronic device showing the claimed design;  
 FIG. 2 is a bottom rear perspective view thereof;  
 FIG. 3 is a front view thereof;  
 FIG. 4 is a rear view thereof;  
 FIG. 5 is a left side view thereof;  
 FIG. 6 is a right side view thereof;

(Continued)



# US D962,936 S

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FIG. 7 is a top view thereof;  
 FIG. 8 is a bottom view thereof; and,  
 FIG. 9 is a bottom front perspective view thereof showing the electronic device in an environment in which it may be used.  
 The broken lines in the figures show portions of the electronic device and environment that form no part of the claimed design.

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D947,842	S	*	4/2022	Akana	.....	D14/344
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D949,146	S	*	4/2022	Akana	.....	D14/344
D953,324	S	*	5/2022	Akana	.....	D14/344

## 1 Claim, 7 Drawing Sheets

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 a continuation of application No. 29/684,825, filed on Mar. 25, 2019, now Pat. No. Des. 917,470, which is a continuation of application No. 29/654,754, filed on Jun. 27, 2018, now Pat. No. Des. 882,563.
- (58) **Field of Classification Search**  
 CPC ..... G04G 17/00; G04G 17/045; G04G 17/08; G04G 17/083; G04G 21/00; G04G 21/08; G04G 99/006  
 See application file for complete search history.
- (56) **References Cited**  
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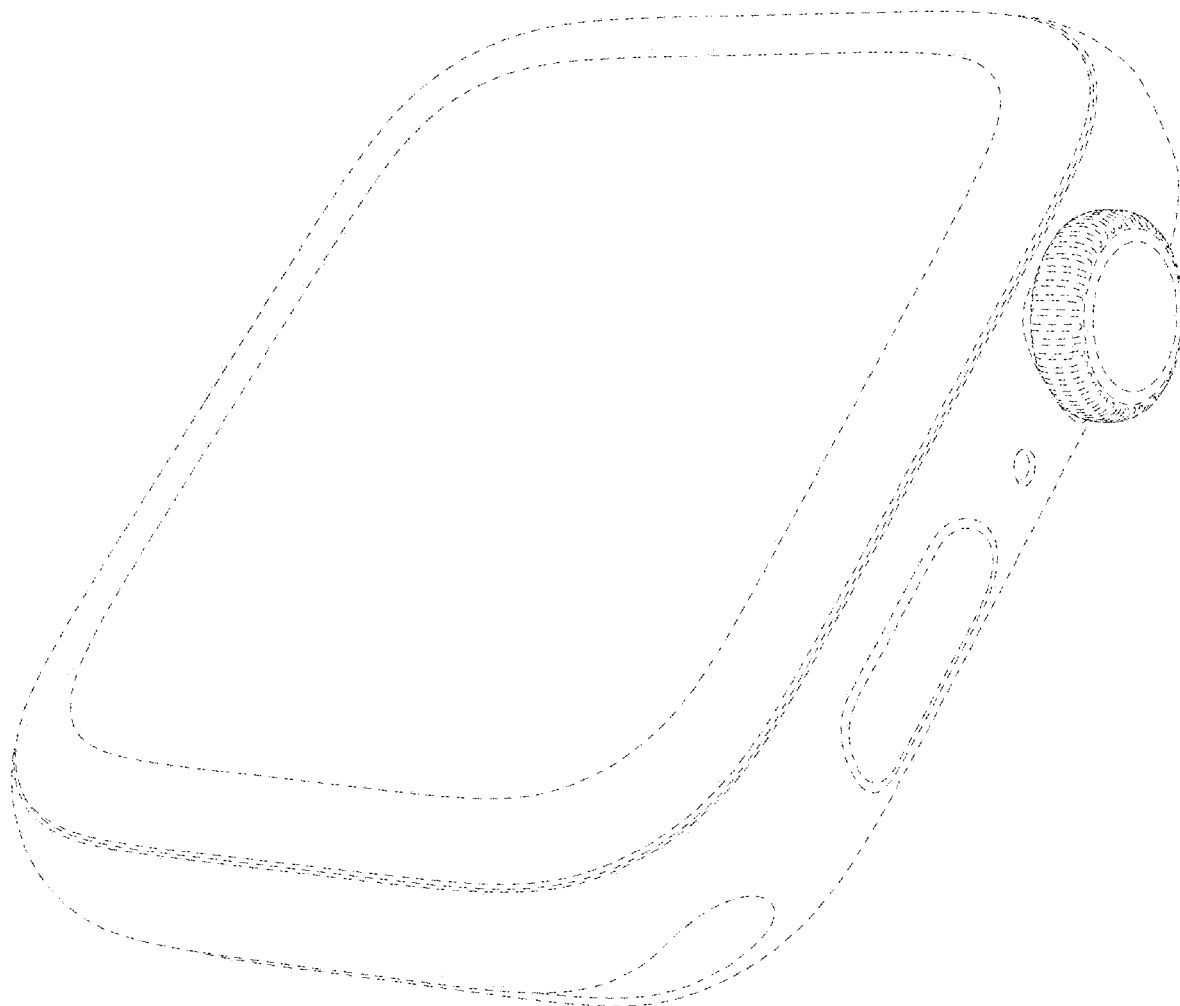
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**U.S. Patent**

**Sep. 6, 2022**

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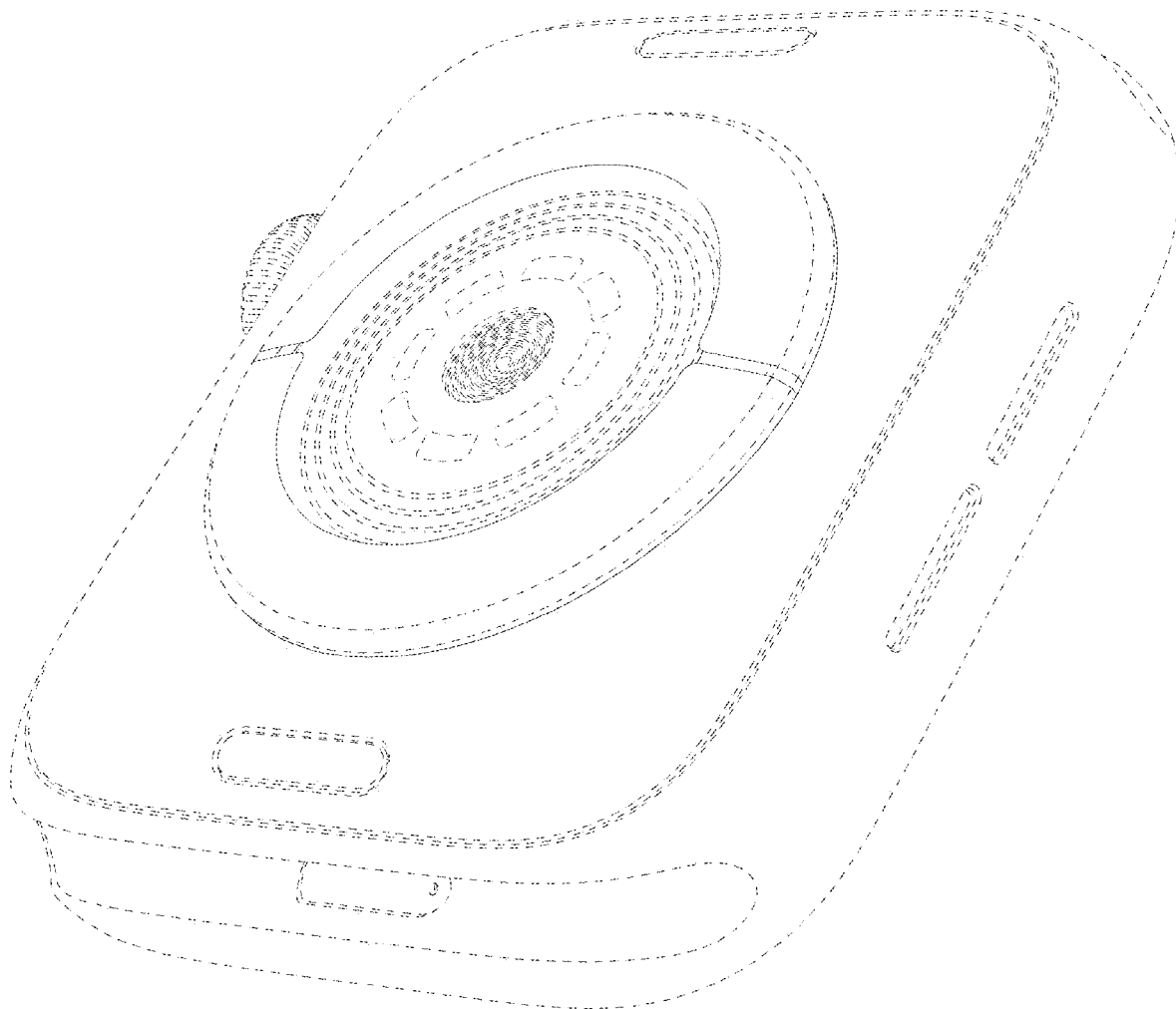
**FIG. 1**

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**Sep. 6, 2022**

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**FIG. 2**

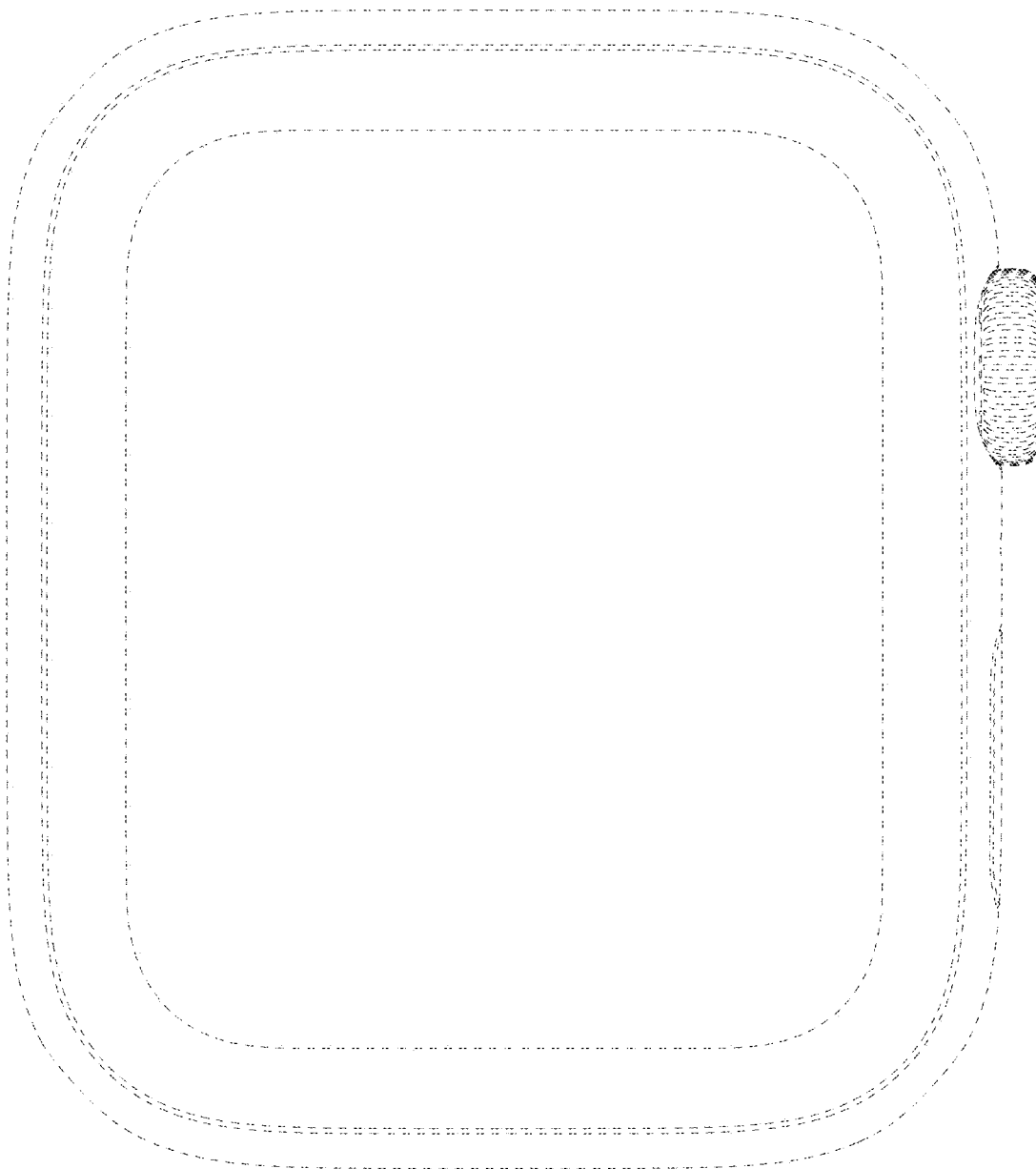


**U.S. Patent**

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**US D962,936 S**



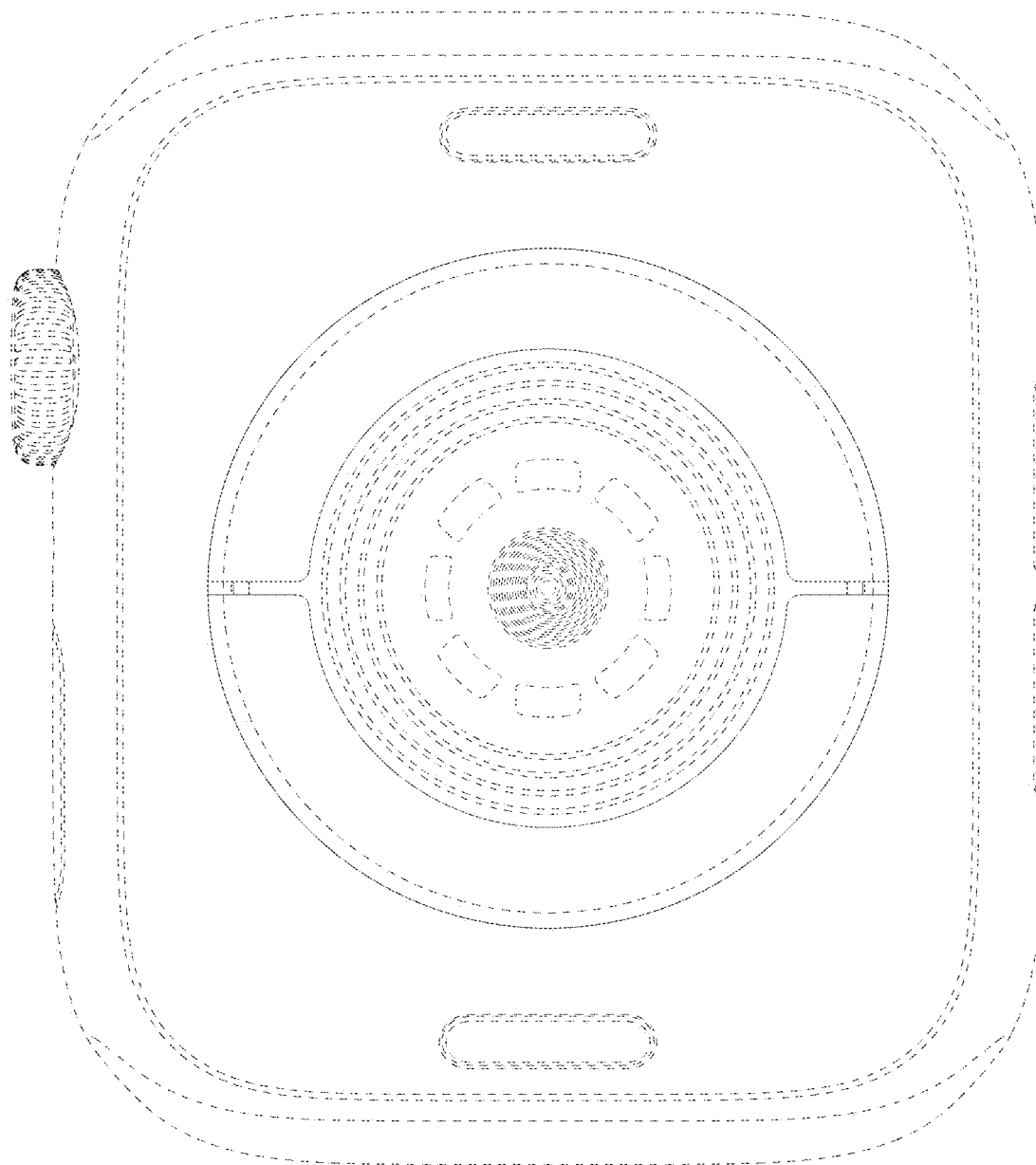
**FIG. 3**

**U.S. Patent**

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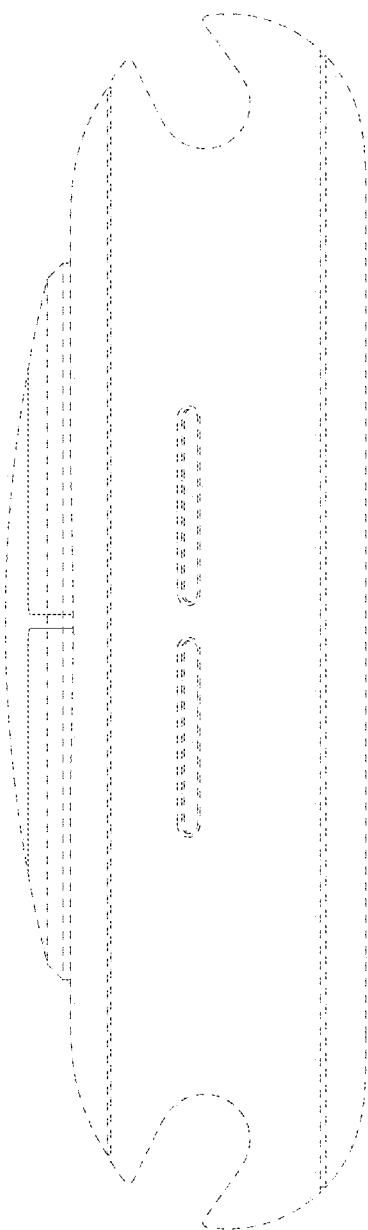
**FIG. 4**

**U.S. Patent**

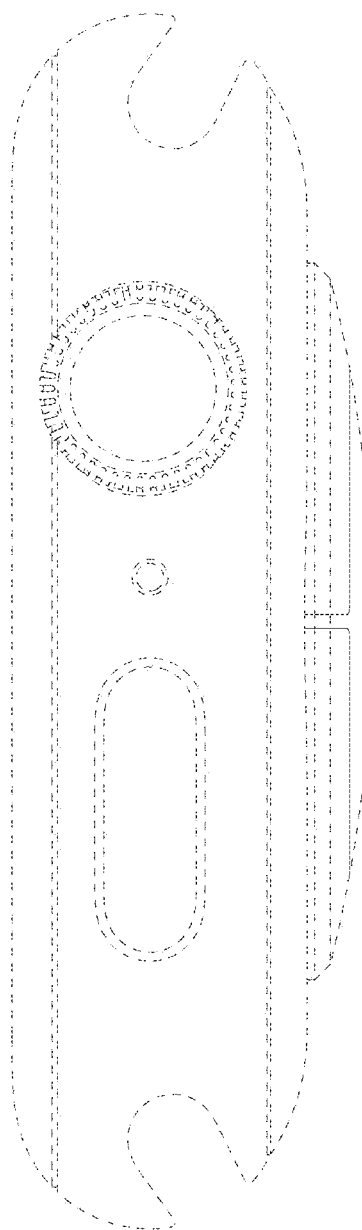
**Sep. 6, 2022**

**Sheet 5 of 7**

**US D962,936 S**



**FIG. 5**



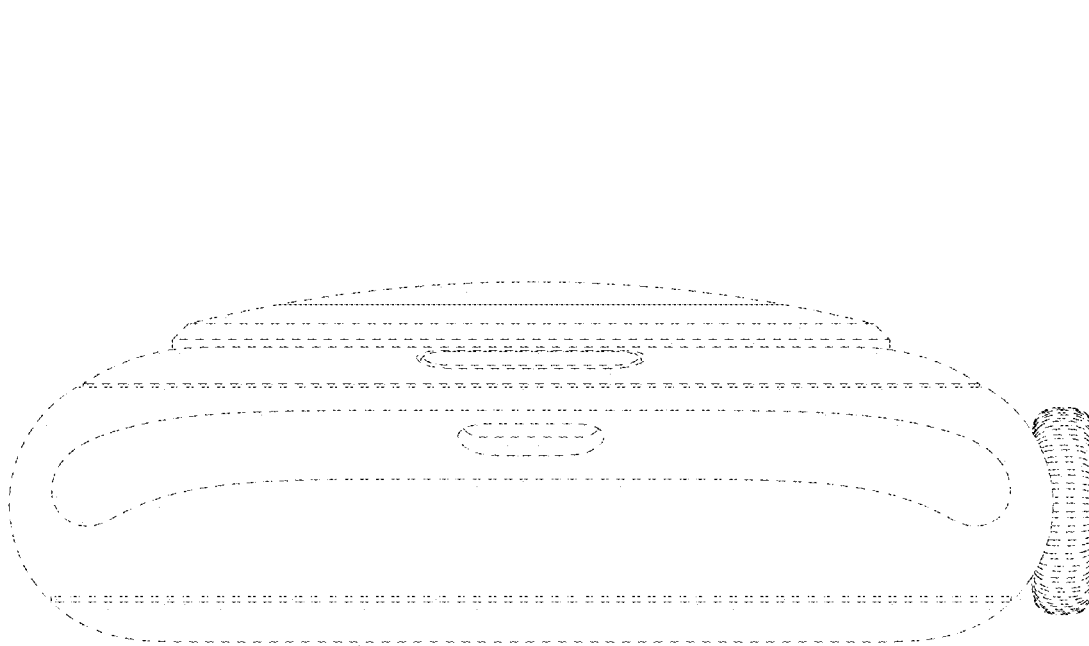
**FIG. 6**

**U.S. Patent**

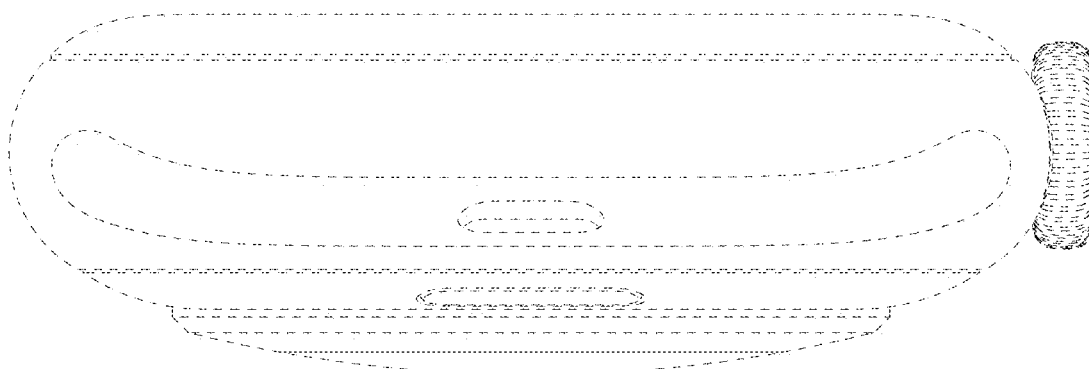
**Sep. 6, 2022**

**Sheet 6 of 7**

**US D962,936 S**



**FIG. 7**



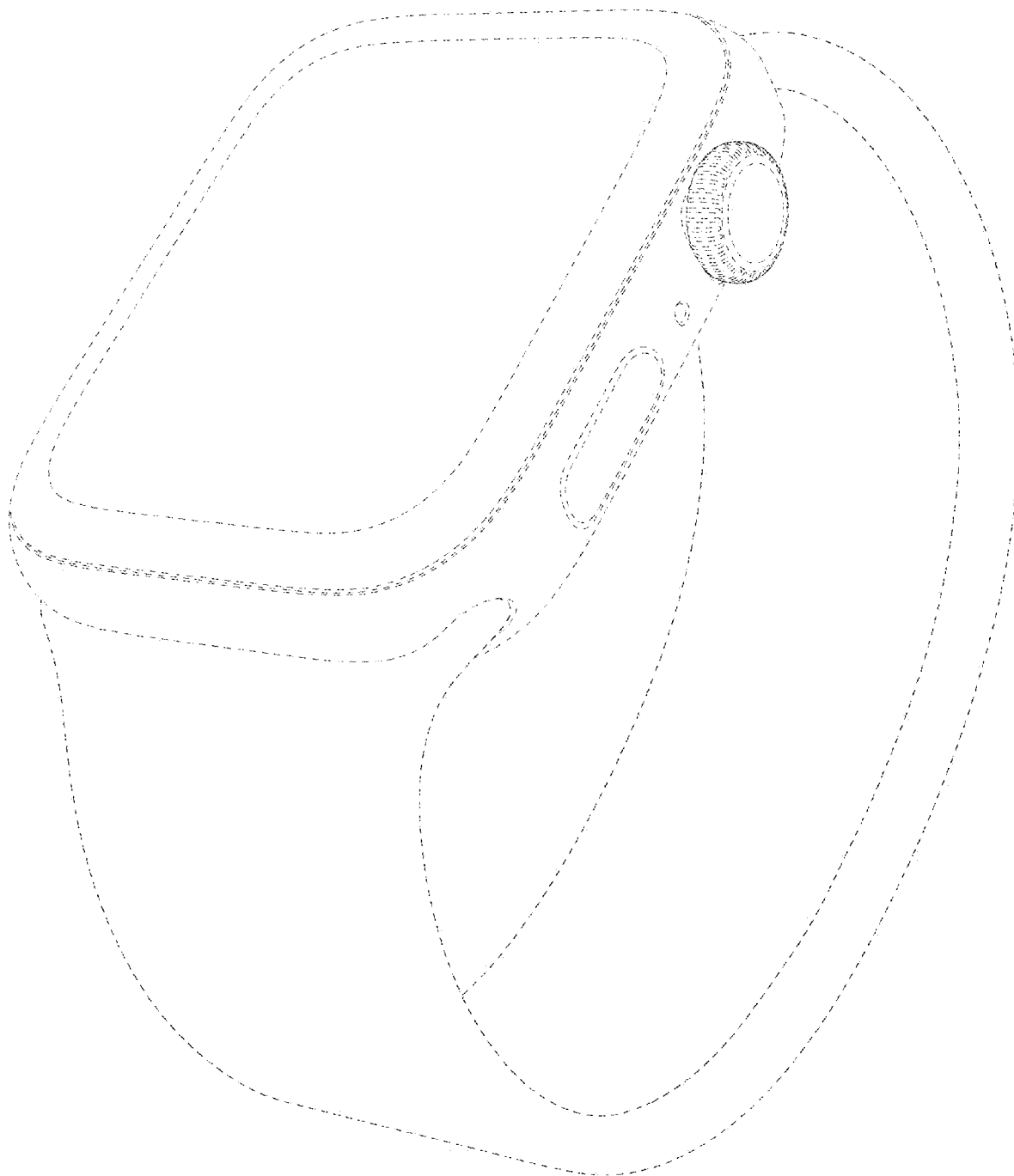
**FIG. 8**

**U.S. Patent**

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**US D962,936 S**



**FIG. 9**

# **EXHIBIT 4**



US00D735131S

(12) **United States Design Patent**  
**Akana et al.**

(10) **Patent No.:** **US D735,131 S**

(45) **Date of Patent:** **\*\* Jul. 28, 2015**

(54) **CHARGER**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

(72) Inventors: **Jody Akana**, San Francisco, CA (US);  
**Bartley K. Andre**, Palo Alto, CA (US);  
**Shota Aoyagi**, San Francisco, CA (US);  
**Anthony Michael Ashcroft**, San Francisco, CA (US); **Jeremy Bataillou**, San Francisco, CA (US); **Daniel J. Coster**, San Francisco, CA (US);  
**Daniele De Iuliis**, San Francisco, CA (US); **M. Evans Hankey**, San Francisco, CA (US); **Julian Hoenig**, San Francisco, CA (US); **Richard P. Howarth**, San Francisco, CA (US); **Jonathan P. Ive**, San Francisco, CA (US); **Duncan Robert Kerr**, San Francisco, CA (US);  
**Marc A. Newson**, London (GB); **Matthew Dean Rohrbach**, San Francisco, CA (US); **Peter Russell-Clarke**, San Francisco, CA (US); **Benjamin Andrew Shaffer**, San Jose, CA (US); **Mikael Silvano**, San Francisco, CA (US); **Christopher J. Stringer**, Woodside, CA (US); **Eugene Antony Whang**, San Francisco, CA (US); **Rico Zörkendörfer**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(\*\*) Term: **14 Years**

(21) Appl. No.: **29/498,998**

(22) Filed: **Aug. 11, 2014**

(51) **LOC (10) Cl.** ..... **13-02**

(52) **U.S. Cl.** ..... **D13/108**  
USPC

(58) **Field of Classification Search**  
USPC ..... D13/107–110, 118–119, 182, 199;  
D14/251, 253, 432, 434; 320/107–115

CPC ..... Y02E 60/12; Y02T 90/14; Y02T 90/122;  
Y02T 90/128; Y02T 90/163; H02J 7/025;  
H02J 7/0042; H02J 7/0044; H02J 7/0045;  
H02J 7/0003; H01F 38/14; H01R 13/6675;  
H01M 2/1022; H01M 2/1055; H01M 10/44;  
H01M 10/46; H01M 10/425; B60L 11/182  
See application file for complete search history.

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*Primary Examiner* — Rosemary K Tarca

(74) *Attorney, Agent, or Firm* — Sterne, Kessler, Goldstein & Fox P.L.L.C.

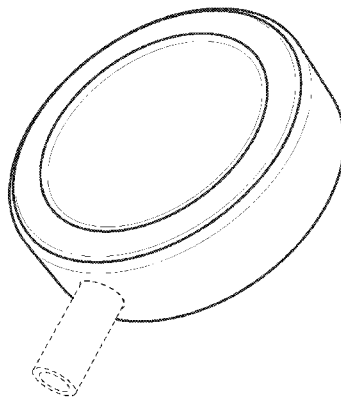
(57) **CLAIM**

The ornamental design for a charger, as shown and described.

**DESCRIPTION**

FIG. 1 is a bottom front perspective view of a charger showing our new design;  
FIG. 2 is a bottom rear perspective view thereof;  
FIG. 3 is a front view thereof;  
FIG. 4 is a rear view thereof;  
FIG. 5 is a left side view thereof;  
FIG. 6 is a right side view thereof;  
FIG. 7 is a top view thereof;  
FIG. 8 is a bottom view thereof;  
FIG. 9 is a perspective view thereof showing the charger in an environment in which it may be used;  
FIG. 10 is a perspective view thereof showing the charger in another environment in which it may be used; and,  
FIG. 11 is a perspective view thereof showing the charger in another environment in which it may be used.  
The broken lines in the Figures show portions of the charger and environment that form no part of the claimed design. The shade lines in the Figures show contour and not surface ornamentation.

**1 Claim, 5 Drawing Sheets**



US D735,131 S

Page 2

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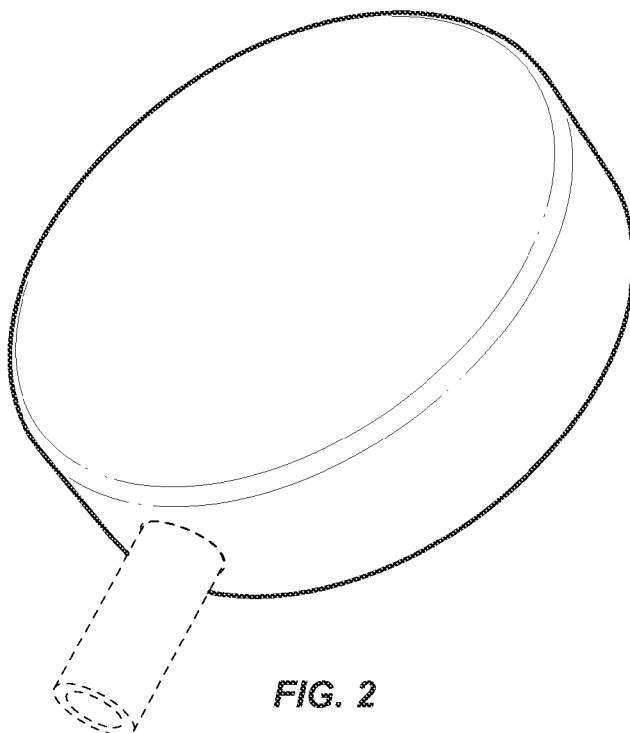
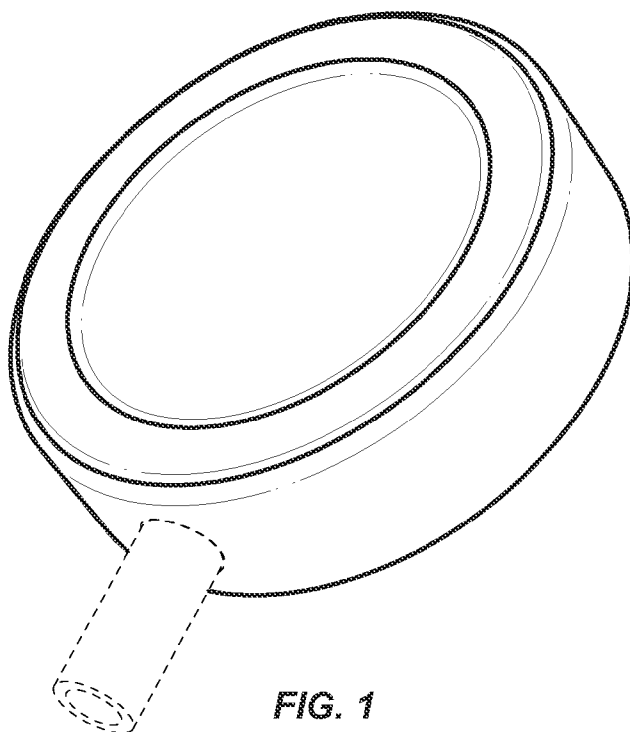


**U.S. Patent**

**Jul. 28, 2015**

**Sheet 1 of 5**

**US D735,131 S**

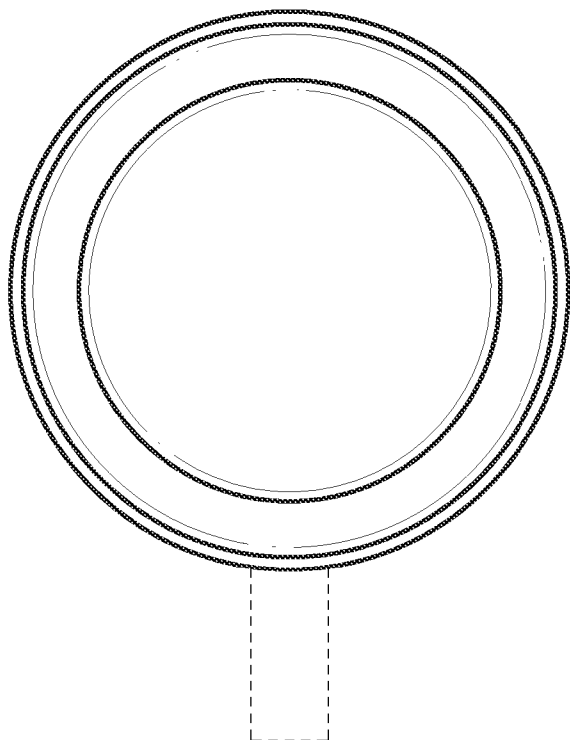


**U.S. Patent**

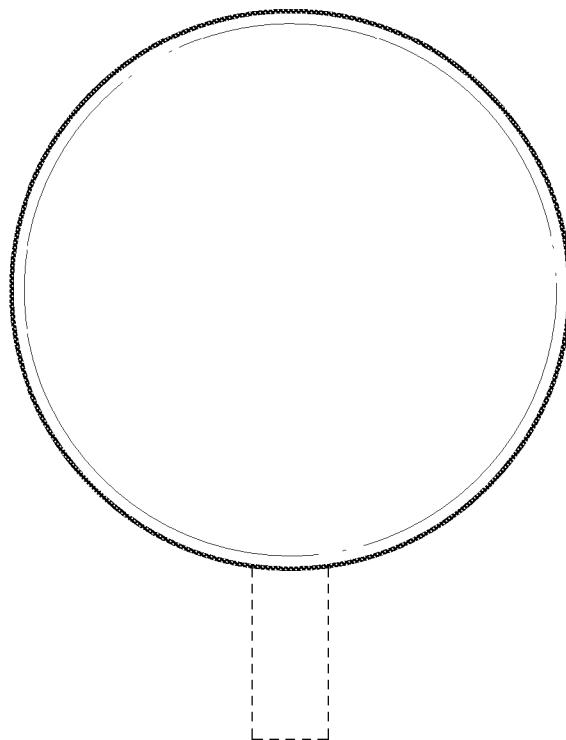
**Jul. 28, 2015**

**Sheet 2 of 5**

**US D735,131 S**



**FIG. 3**



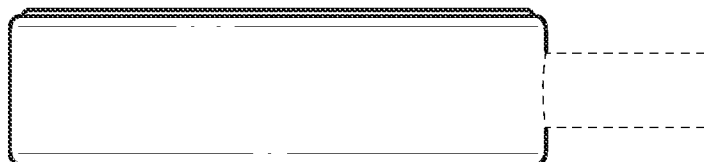
**FIG. 4**

**U.S. Patent**

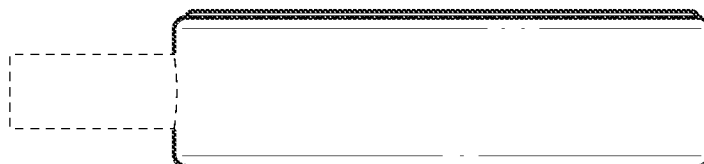
**Jul. 28, 2015**

**Sheet 3 of 5**

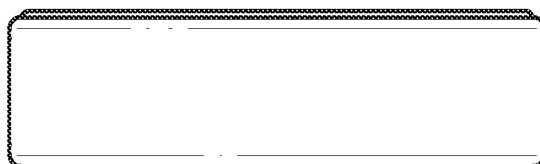
**US D735,131 S**



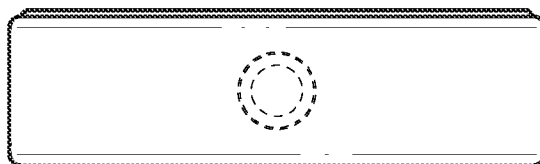
**FIG. 5**



**FIG. 6**



**FIG. 7**



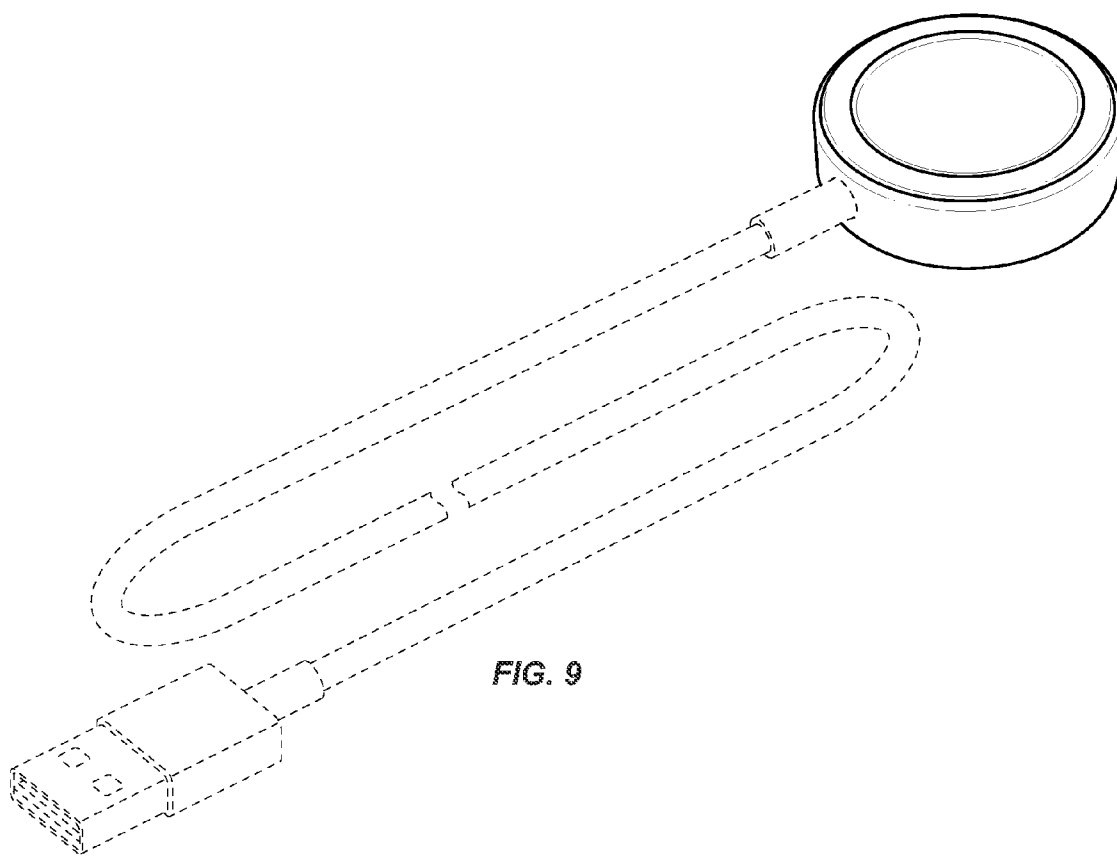
**FIG. 8**

**U.S. Patent**

**Jul. 28, 2015**

**Sheet 4 of 5**

**US D735,131 S**

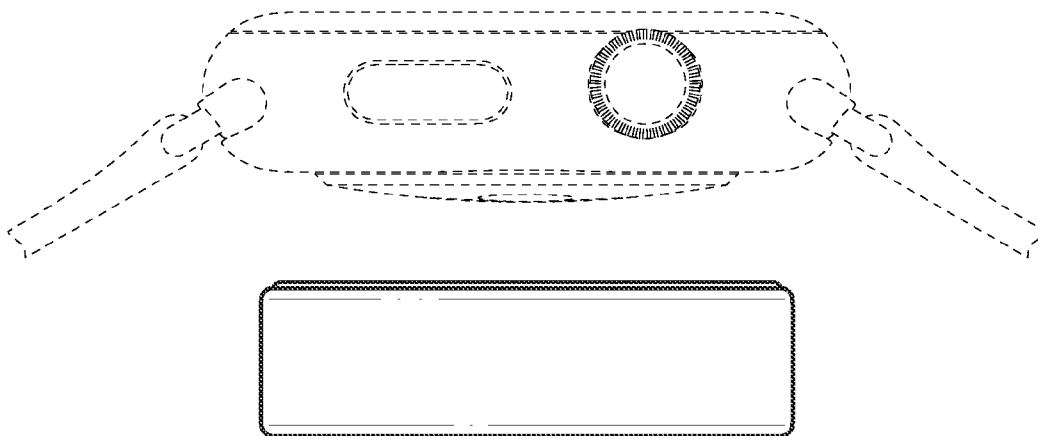


**U.S. Patent**

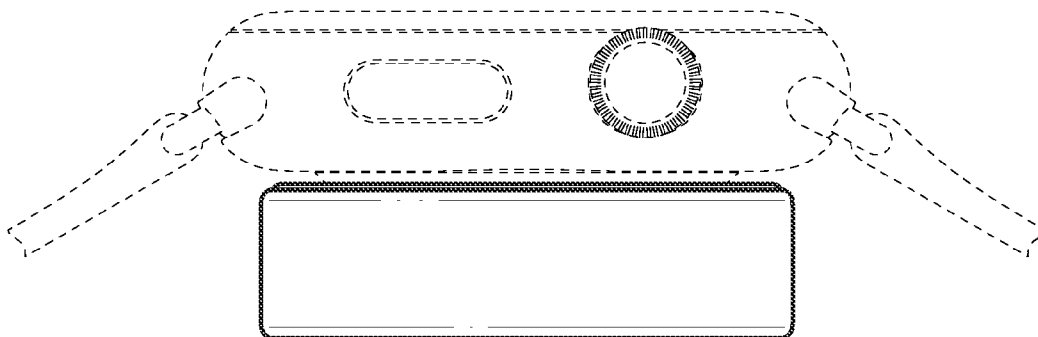
**Jul. 28, 2015**

**Sheet 5 of 5**

**US D735,131 S**



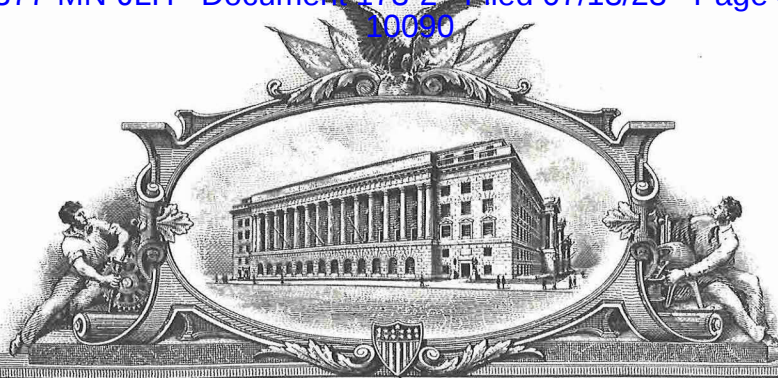
**FIG. 10**



**FIG. 11**

# **EXHIBIT 5**

8338933



# THE UNITED STATES OF AMERICA

**TO ALL TO WHOM THESE PRESENTS SHALL COME:**

UNITED STATES DEPARTMENT OF COMMERCE  
United States Patent and Trademark Office

January 26, 2023

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM  
THE RECORDS OF THIS OFFICE OF:

PATENT NUMBER: 10,076,257

ISSUE DATE: September 18, 2018

By Authority of the  
Under Secretary of Commerce for Intellectual Property  
and Director of the United States Patent and Trademark Office

*W. Montgomery*  
Wanda Montgomery  
Certifying Officer





US010076257B2

(12) **United States Patent**  
**Lin et al.**

(10) **Patent No.:** **US 10,076,257 B2**  
(45) **Date of Patent:** **\*Sep. 18, 2018**

(54) **SEAMLESSLY EMBEDDED HEART RATE MONITOR**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

(72) Inventors: **Gloria Lin**, San Ramon, CA (US);  
**Taido L. Nakajima**, Cupertino, CA (US); **Pareet Rahul**, Markham (CA);  
**Andrew B. Hodge**, Palo Alto, CA (US)

(73) Assignee: **APPLE INC.**, Cupertino, CA (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 88 days.  
  
This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/136,658**

(22) Filed: **Dec. 20, 2013**

(65) **Prior Publication Data**  
US 2014/0171776 A1 Jun. 19, 2014

**Related U.S. Application Data**

(63) Continuation of application No. 12/358,905, filed on Jan. 23, 2009, now Pat. No. 8,615,290.  
(Continued)

(51) **Int. Cl.**  
**A61B 5/117** (2016.01)  
**A61B 5/04** (2006.01)  
(Continued)

(52) **U.S. Cl.**  
CPC ..... **A61B 5/04012** (2013.01); **A61B 5/0245** (2013.01); **A61B 5/02438** (2013.01);  
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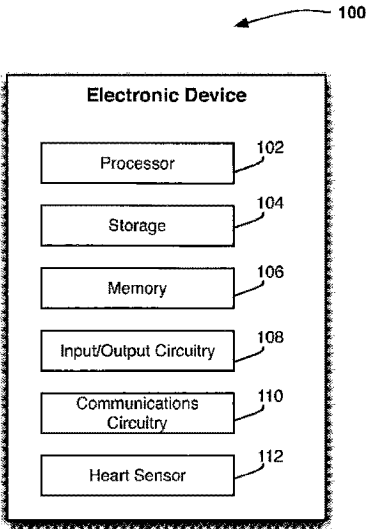
(58) **Field of Classification Search**  
CPC .... A61B 5/02438; A61B 5/0245; A61B 5/404  
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JP 2008073462 4/2008  
*Primary Examiner* — Alyssa M Alter  
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(57) **ABSTRACT**  
  
This is directed to an electronic device having an integrated sensor for detecting a user's cardiac activity and cardiac electrical signals. The electronic device can include a heart sensor having several leads for detecting a user's cardiac signals. The leads can be coupled to interior surfaces of the electronic device housing to hide the sensor from view, such that electrical signals generated by the user can be transmitted from the user's skin through the electronic device housing to the leads. In some embodiments, the leads can be coupled to pads placed on the exterior of the housing. The pads and housing can be finished to ensure that the pads are not visibly or haptically distinguishable on the device, thus improving the aesthetic qualities of the device. Using the detected signals, the electronic device can identify or authenticate the user and perform an operation based on the identity of the user. In some embodiments, the electronic device can determine the user's mood from the cardiac signals and provide data related to the user's mood.

**22 Claims, 6 Drawing Sheets**





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*A61B 5/0245* (2006.01)

*A61B 5/0404* (2006.01)

*A61B 5/0408* (2006.01)

*A61B 5/044* (2006.01)

*A61B 5/00* (2006.01)

(52) **U.S. Cl.**

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(2013.01); *A61B 5/04085* (2013.01); *A61B*  
*5/6898* (2013.01); *A61B 2560/0468* (2013.01)

(58) **Field of Classification Search**

USPC ..... 607/36; 600/509  
See application file for complete search history.

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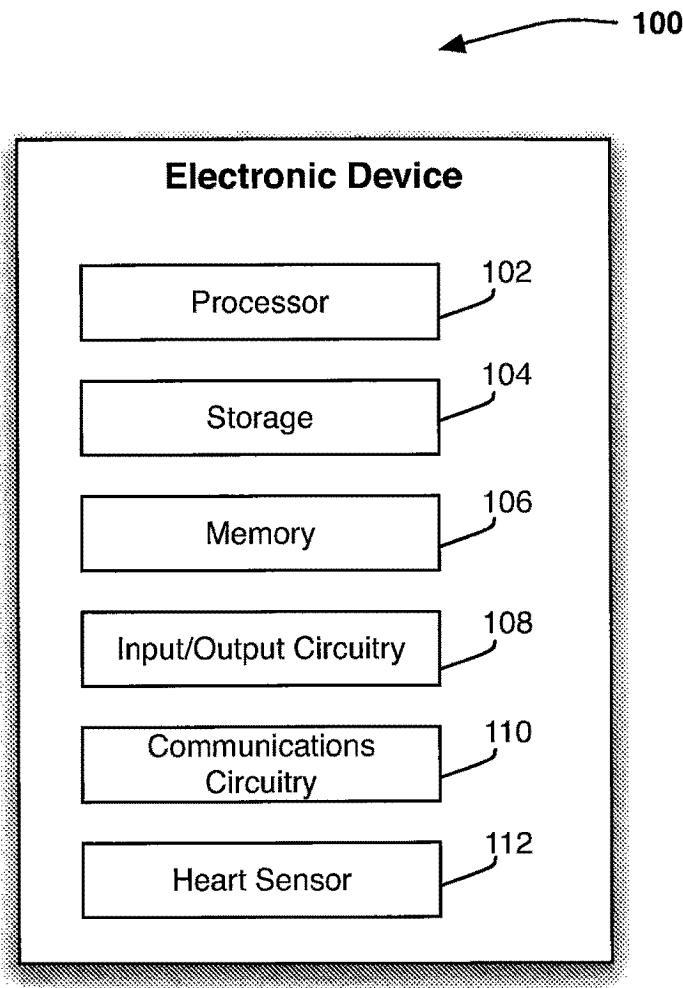
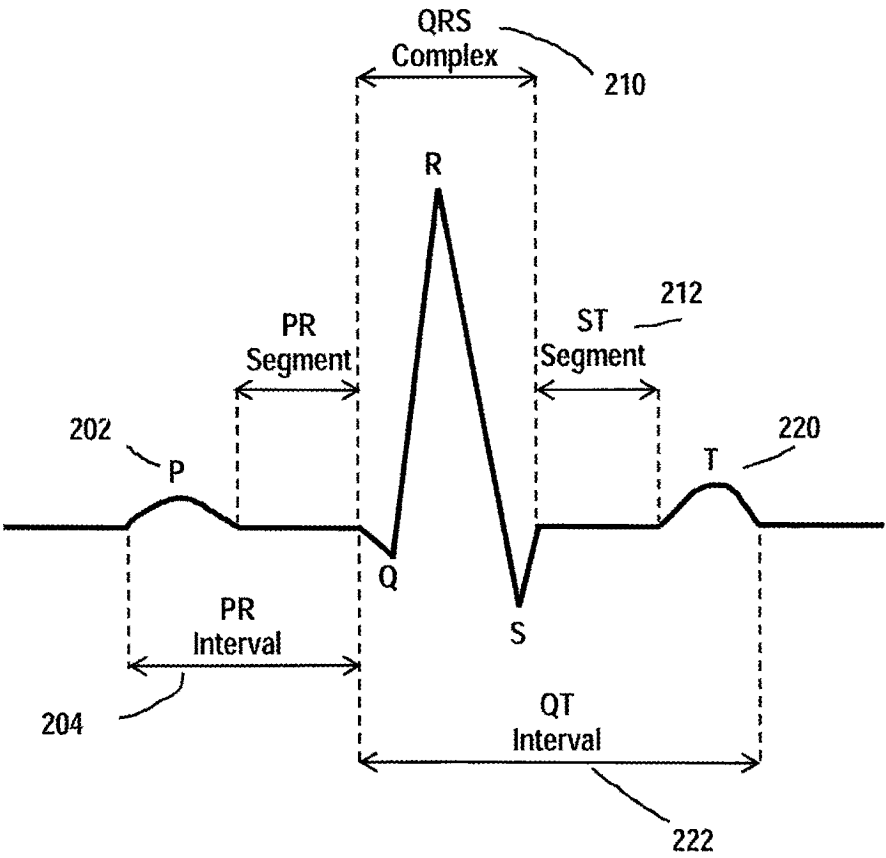


FIG. 1



200  
FIG. 2

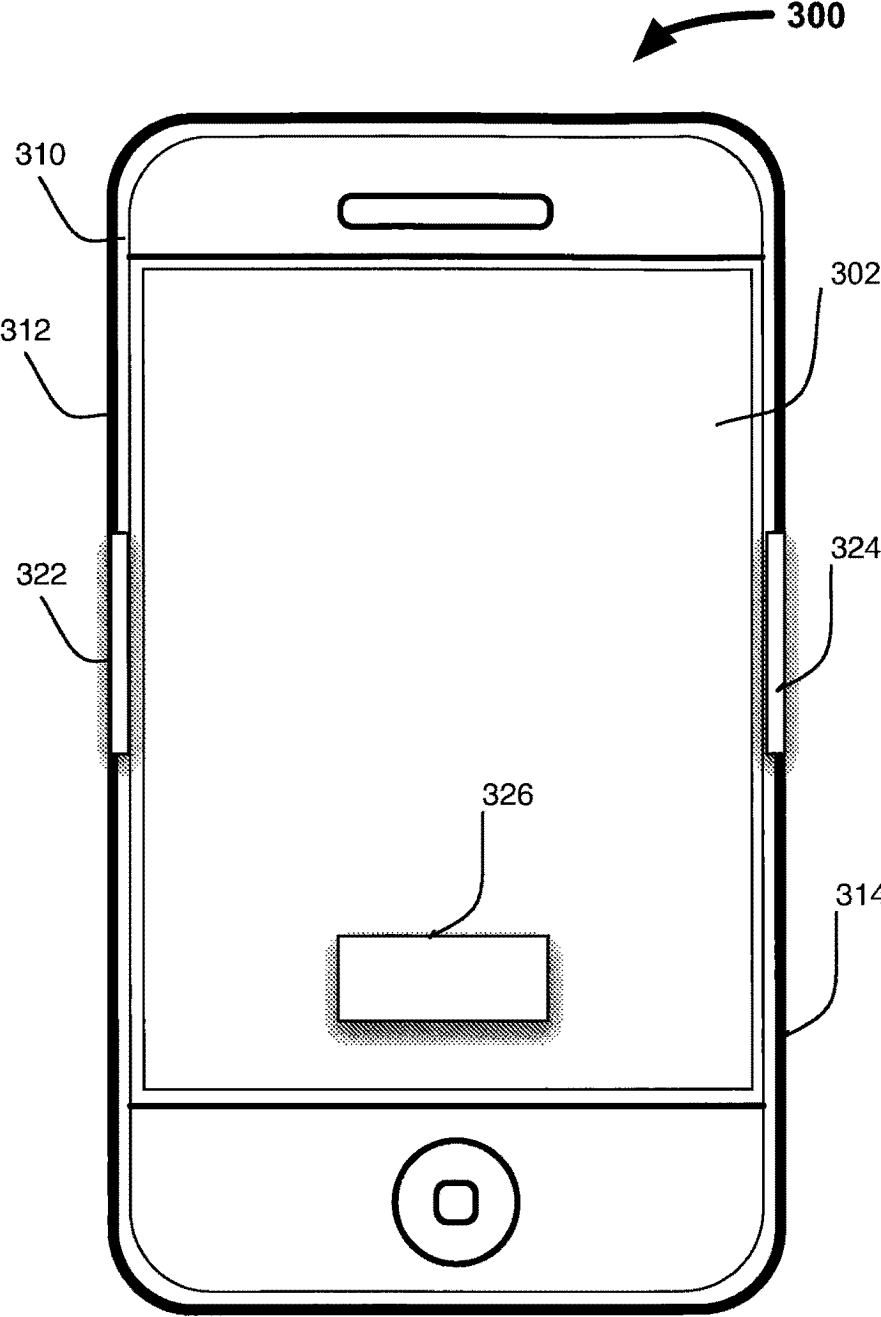


FIG. 3

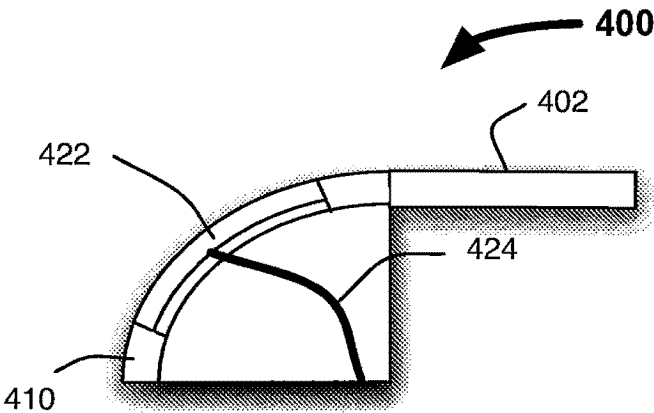


FIG. 4A

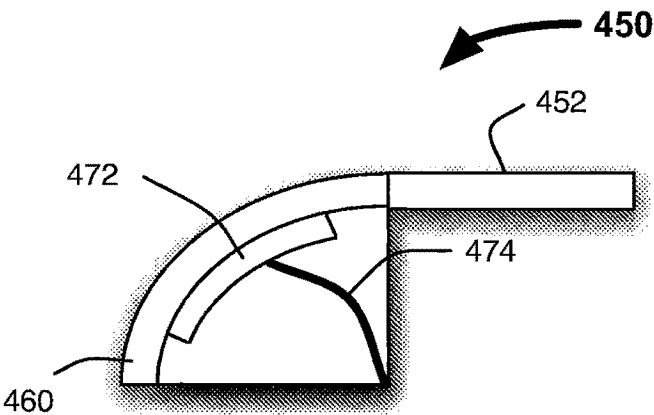


FIG. 4B

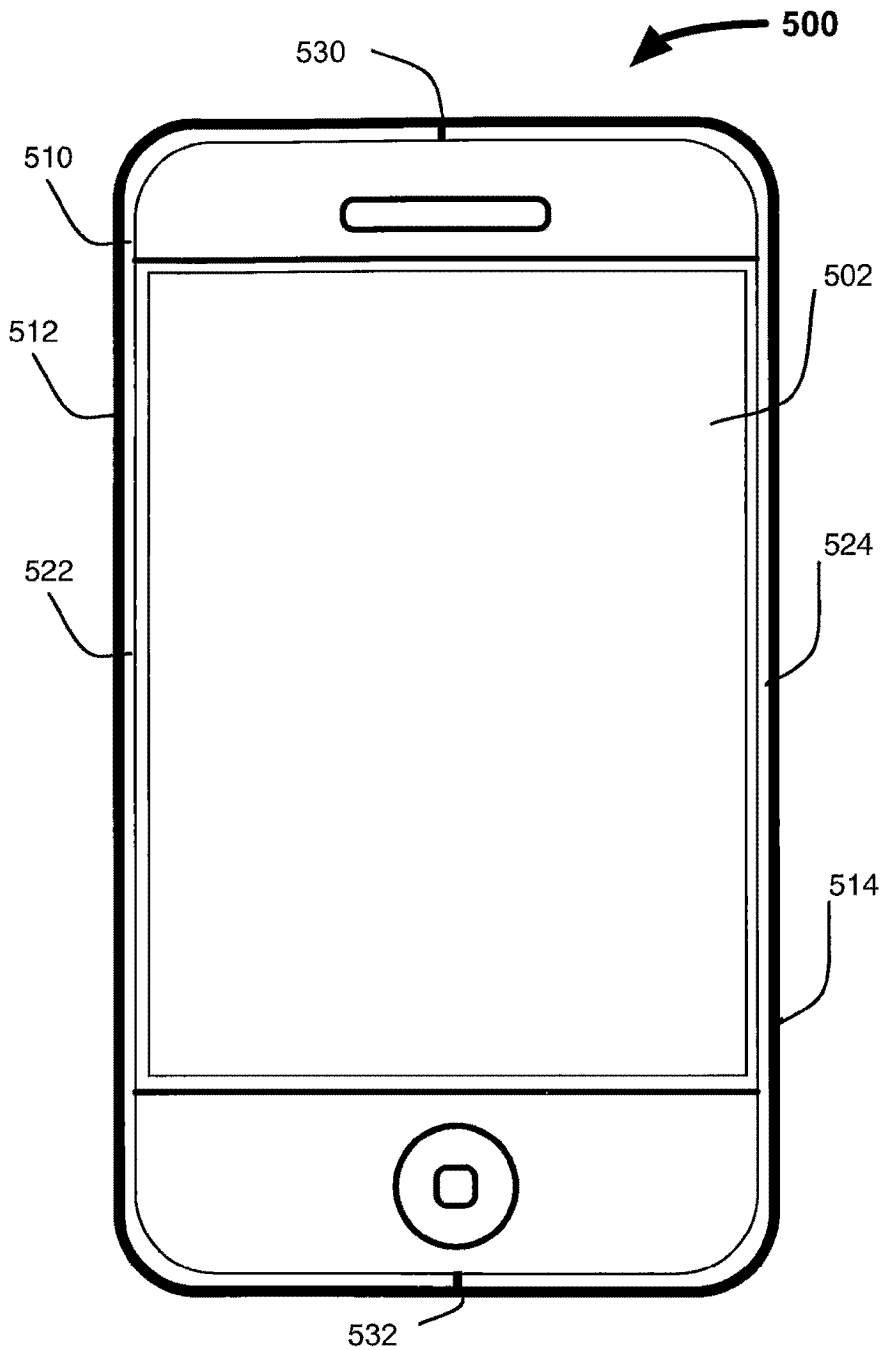


FIG. 5

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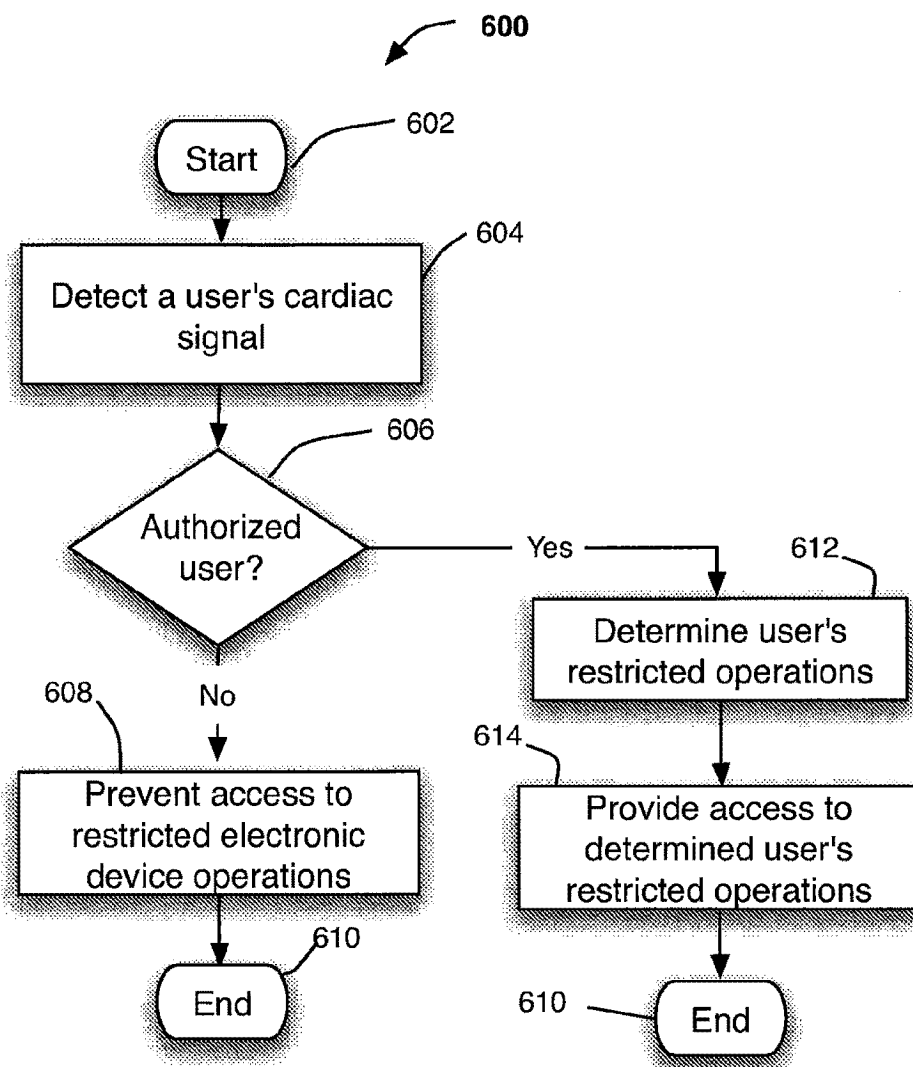


FIG. 6

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# SEAMLESSLY EMBEDDED HEART RATE MONITOR

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 12/358,905, filed Jan. 23, 2009 (now U.S. Pat. No. 8,615,290), which claims priority to U.S. Provisional Patent Application No. 61/111,498, filed Nov. 5, 2008. Each of these earlier applications is incorporated by reference herein in its entirety.

## BACKGROUND OF THE INVENTION

This is directed to providing a seamless heart-rate monitor in an electronic device.

Many electronic devices are used to store personal or confidential information. In particular, portable electronic devices such as cellular telephones, personal assistants, and music players are often used to store or access e-mail, contact lists, communications history, remotely accessed accounts (e.g., telephone, banking or credit card accounts), or other information that a user may regard as personal or private. In addition, several users may use the same electronic device. For example, several users in a household may use the same computer or portable music player. As another example, a user may lend an electronic device to a friend (e.g., lend an iPod, available from Apple Inc. to a friend for a workout or a trip). To enhance each user's experience with the electronic device, the electronic device can include several profiles that can be loaded and provided to the users of the device. Each profile can be associated with a particular user, and include several settings that allow the electronic device interface user interaction components, and available data or applications to be personalized for the user.

The electronic device can use several approaches to identify the user of the electronic device and provide access to the user's private and personal information, or to load the user's personal profile. In some embodiments, the electronic device can identify or authenticate a user based on an input provided by the user, such as a password or key provided using an input mechanism. In some embodiments, the electronic device can include one or more sensors operative to detect a fingerprint, voice print, facial features, or other biometric characteristics of a user.

Other biometric-based approaches can be used to authenticate a user. In some embodiments, an electronic device can authenticate a user based on the attributes of the user's heartbeat. For example, the durations of particular portions of a user's heart rhythm, or the relative size of peaks of a user's electrocardiogram (EKG) can be processed and compared to a stored profile to authenticate a user of the device. To detect a user's heartbeat or heart rhythm, however, the electronic device must provide at least two leads that the user contacts to detect the user's cardiac signals. Although the leads can simply be placed on the exterior surface of the device housing, for example in a defined location where the user may place a finger, this approach is not aesthetically pleasing, and may cause some prospective buyers to consider other devices. In addition, such an approach may require the user to perform a specific authentication action—viz., placing a finger on the one or more leads, then unlocking or accessing the electronic device features (e.g., by moving a slider across the screen). This additional step

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may in fact be so encumbering that users disable the authentication feature and instead use an unsecured electronic device.

## SUMMARY OF THE INVENTION

This is directed to an electronic device having a seamlessly integrated cardiac sensor. The cardiac sensor can be integrated in any suitable portion of the electronic device, including for example a portion with which the user is typically in contact (e.g., an input mechanism or a housing held by the user), or metallic or conductive portions of the device.

The electronic device can include any suitable type of electronic device, including for example a portable electronic device that the user may hold in hand (e.g., a portable media player or a cellular telephone), a larger portable electronic device (e.g., a laptop computer), or a substantially fixed electronic device. The electronic device may include software or hardware operative to process the output of a cardiac sensor to extract, from the received output, characteristics of the user's heartbeat, heart rate, or other cardiac signals. For example, the electronic device may extract one or more characteristic durations associated with the user's heart rate. As another example, the electronic device may extract one or more characteristic amplitudes or amplitude ratios associated with the user's heart rate.

Once the electronic device has identified one or more characteristics of the user's heart rate, heartbeat, or other cardiac signals, the electronic device can compare the one or more identified characteristics with cardiac signal characteristics of authorized users that have been stored in memory. In response to determining that the identified characteristics correspond to those of an authorized user (e.g., match those stored in memory), the electronic device can provide the user with access to the electronic device and load the identified user's personal settings and data.

To determine the user's heart rate, heartbeat, or other cardiac signals, the electronic device can include one or more sensors embedded in the device. The one or more sensors can include leads for receiving electrical signals from the user's heart. For example, the one or more sensors can include leads associated with the user's left and right sides, and lead associated with the ground. To provide an electrical signal from the user to the processing circuitry, the leads can be exposed such that the user may directly contact the leads, or may instead or in addition be coupled to an electrically conductive portion of the device enclosure (e.g., a metallic bezel or housing forming the exterior of the device).

Because each electronic device can include several leads, the leads may be electrically isolated to avoid shorting or interference among leads. In some embodiments, an electrically isolating component can be inserted between adjacent leads. Alternatively, if the electronic device enclosure is constructed from a material having insufficient conductivity for transmitting detected cardiac electrical signals, the distance along the enclosure between adjacent leads can be sufficient to isolate the leads. In addition, to ensure that the aesthetic appeal and appearance of the electronic device is retained, one or more of the isolating components, the leads themselves, and the device enclosure can be finished using a suitable process to disguise the leads.

In some embodiments, if the electrical conductivity of portions of the electronic device enclosure and the leads are suitably selected and designed, the leads can be positioned underneath the exterior surface of the enclosure while pro-



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viding sufficient conductivity for detecting cardiac electrical signals and avoiding shorting or interference between adjacent leads. For example, the sensor leads can be constructed from a silver based compound having high electrical conductivity, while the electronic device enclosure can be constructed from steel and aluminum, both having lower electrical conductivity. By placing several leads at substantially larger distances apart along the electronic device enclosure than the thickness of the enclosure, electronic signals can be transmitted through the steel or aluminum enclosure to a silver based lead underneath the enclosure, but not along the surface of the enclosure to cause adjacent leads to short.

### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features of the present invention, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic view of an illustrative electronic device for receiving the output of one or more sensors in accordance with one embodiment of the invention;

FIG. 2 is a graphical representation of illustrative electrical activity of a heart during a heartbeat;

FIG. 3 is a schematic view of an illustrative electronic device having several integrated leads in accordance with one embodiment of the invention;

FIG. 4A is a cross-sectional view of an illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention;

FIG. 4B is a cross-sectional view of another illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention;

FIG. 5 is a schematic view of an illustrative electronic device using portions of the bezel as leads in accordance with one embodiment of the invention; and

FIG. 6 is a flowchart of an illustrative process for performing an electronic device operation based on a user's cardiac signal in accordance with one embodiment of the invention.

### DETAILED DESCRIPTION

FIG. 1 is a schematic view of an illustrative electronic device for receiving the output of one or more sensors in accordance with one embodiment of the invention. Electronic device 100 can include control circuitry 102, storage 104, memory 106, input/output circuitry 108, communications circuitry 110, and heart sensor 112. In some embodiments, one or more of electronic device components 100 can be combined or omitted (e.g., combine storage 104 and memory 106). In some embodiments, electronic device 100 can include other components not combined or included in those shown in FIG. 1 (e.g., motion detection components, a power supply such as a battery or kinetics, a display, bus, or input mechanism), or several instances of the components shown in FIG. 1. For the sake of simplicity, only one of each of the components is shown in FIG. 1.

Control circuitry 102 can include any processing circuitry or processor operative to control the operations and performance of electronic device 100. For example, control circuitry 100 can be used to run operating system applications, firmware applications, media playback applications, media editing applications, or any other application. In some

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embodiments, the control circuitry can drive a display and process inputs received from a user interface.

Storage 104 can include, for example, one or more storage mediums including a hard-drive, solid state drive, flash memory, permanent memory such as ROM, any other suitable type of storage component, or any combination thereof. Storage 104 can store, for example, media data (e.g., music and video files), application data (e.g., for implementing functions on device 100), firmware, user preference information data (e.g., media playback preferences), authentication information (e.g. libraries of data associated with authorized users), lifestyle information data (e.g., food preferences), exercise information data (e.g., information obtained by exercise monitoring equipment), transaction information data (e.g., information such as credit card information), wireless connection information data (e.g., information that can enable electronic device 100 to establish a wireless connection), subscription information data (e.g., information that keeps track of podcasts or television shows or other media a user subscribes to), contact information data (e.g., telephone numbers and email addresses), calendar information data, and any other suitable data or any combination thereof.

Memory 106 can include cache memory, semi-permanent memory such as RAM, and/or one or more different types of memory used for temporarily storing data. In some embodiments, memory 106 can also be used for storing data used to operate electronic device applications, or any other type of data that can be stored in storage 104. In some embodiments, memory 106 and storage 104 can be combined as a single storage medium.

Input/output circuitry 108 can be operative to convert (and encode/decode, if necessary) analog signals and other signals into digital data. In some embodiments, input/output circuitry 108 can also convert digital data into any other type of signal, and vice-versa. For example, input/output circuitry 108 can receive and convert physical contact inputs (e.g., from a multi-touch screen), physical movements (e.g., from a mouse or sensor), analog audio signals (e.g., from a microphone), or any other input. The digital data can be provided to and received from processor 102, storage 104, memory 106, heart sensor 112, or any other component of electronic device 100. Although input/output circuitry 108 is illustrated in FIG. 1 as a single component of electronic device 100, several instances of input/output circuitry can be included in electronic device 100.

Electronic device 100 can include any suitable mechanism or component for allowing a user to provide inputs to input/output circuitry 108. For example, electronic device 100 can include any suitable input mechanism, such as for example, a button, keypad, dial, a click wheel, or a touch screen. In some embodiments, electronic device 100 can include a capacitive sensing mechanism, or a multi-touch capacitive sensing mechanism. Some sensing mechanisms are described in commonly owned U.S. Pat. Nos. 8,479,122 and 8,239,784, both of which are incorporated herein in their entirety.

In some embodiments, electronic device 100 can include specialized output circuitry associated with output devices such as, for example, one or more audio outputs. The audio output can include one or more speakers (e.g., mono or stereo speakers) built into electronic device 100, or an audio component that is remotely coupled to electronic device 100 (e.g., a headset, headphones or earbuds that can be coupled to communications device with a wire or wirelessly).

In some embodiments, I/O circuitry 108 can include display circuitry (e.g., a screen or projection system) for

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providing a display visible to the user. For example, the display circuitry can include a screen (e.g., an LCD screen) that is incorporated in electronics device 100. As another example, the display circuitry can include a movable display or a projecting system for providing a display of content on a surface remote from electronic device 100 (e.g., a video projector). In some embodiments, the display circuitry can include a coder/decoder (Codec) to convert digital media data into analog signals. For example, the display circuitry (or other appropriate circuitry within electronic device 100) can include video Codecs, audio Codecs, or any other suitable type of Codec.

The display circuitry also can include display driver circuitry, circuitry for driving display drivers, or both. The display circuitry can be operative to display content (e.g., media playback information, application screens for applications implemented on the electronic device, information regarding ongoing communications operations, information regarding incoming communications requests, or device operation screens) under the direction of control circuitry 102. Alternatively, the display circuitry can be operative to provide instructions to a remote display (e.g., display 130, FIG. 1).

Communications circuitry 110 can include any suitable communications circuitry operative to connect to a communications network and to transmit communications (e.g., voice or data) from communications device 100 to other devices within the communications network. Communications circuitry 110 can be operative to interface with the communications network using any suitable communications protocol such as, for example, Wi-Fi (e.g., a 802.11 protocol), Bluetooth, radio frequency systems (e.g., 900 MHz, 1.4 GHz, and 5.6 GHz communication systems), infrared, GSM, GSM plus EDGE, CDMA, quadband, and other cellular protocols, VOIP, or any other suitable protocol.

In some embodiments, communications circuitry 110 can be operative to create a communications network using any suitable communications protocol. For example, communications circuitry 110 can create a short-range communications network using a short-range communications protocol to connect to other devices. For example, communications circuitry 110 can be operative to create a local communications network using the Bluetooth® protocol to couple electronic device 100 with a Bluetooth headset.

Electronic device 100 can include one more instances of communications circuitry 110 for simultaneously performing several communications operations using different communications networks, although only one is shown in FIG. 1 to avoid overcomplicating the drawing. For example, electronic device 100 can include a first instance of communications circuitry 110 for communicating over a cellular network, and a second instance of communications circuitry 110 for communicating over Wi-Fi or using Bluetooth®. In some embodiments, the same instance of communications circuitry 110 can be operative to provide for communications over several communications networks.

In some embodiments, electronic device 100 can be coupled a host device for data transfers, synching the communications device, software or firmware updates, providing performance information to a remote source (e.g., providing riding characteristics to a remote server) or performing any other suitable operation that can require electronic device 100 to be coupled to a host device. Several electronic devices 100 can be coupled to a single host device using the host device as a server, and instead or in addition electronic device 100 can be coupled to several host devices

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(e.g., for each of the plurality of the host devices to serve as a backup for data stored in electronic device 100).

Heart sensor 112 can include any suitable sensor operative to detect a user's heartbeat, heart rate, or any other signal generated by the user's heart. In some embodiments, heart sensor 112 can serve as an EKG monitor. Heart sensor 112 can include one or more leads connected to the exterior of the electronic device such that the user may contact one or more of the leads to provide an electrical signal associated with the user's heart to heart sensor 112. The cardiac signals detected by the heart sensor leads can be coupled to a processor incorporated in heart sensor 112, or instead provided to processor 102. The processor may then analyze the received signals and generate, from the received signals, one or more characteristic quantities of the user's heartbeat or heart rate for authentication.

The heart sensor leads can be constructed from any suitable material. In some embodiments, the heart sensor leads can be constructed from a specific material selected for particular conductive properties that permit a more effective transmission of the electrical signals reflecting the user's cardiac activity. For example, the heart sensor leads can be constructed from a silver based compound, which can provide superior conductivity relative to other metallic compounds (e.g., steel or aluminum). In addition, the size and location of the leads can be selected to ensure that sufficient contact is made between the user (e.g., the user's hand or finger) and the leads for cardiac signals to be detected. For example, each lead can include a pad or extended area placed on the outer or inner surface of an electronic device bezel or housing. The pad or extended area can then be coupled to a wire or other connector for providing cardiac signals to a processor for processing. As another example, an entire portion of the electronic device enclosure (e.g., a portion of a bezel or housing) can serve as a lead for the heart sensor. In such embodiments, the portion of the enclosure can be sufficiently electrically isolated from other conductive portions of the electronic device housing to ensure that lead portions of the device do not short. In some embodiments, an accessory coupled to the electronic device can be used to detect a user's heart rate. For example, the leads can be located in one or more earbuds or in a headset, for example as is described in commonly assigned U.S. Publication No. 2008/0076972, which is incorporated by reference herein in its entirety.

Using a heart sensor, the electronic device can detect and analyze the electrical activity of the heart over time. FIG. 2 is a graphical representation of illustrative electrical activity of a heart during a heartbeat. Representation 200 may include a plot of the variation of the heart's electrical potential over time. A typical heartbeat may include several variations of electrical potential, which may be classified into waves and a complex. For example, representation 200 can include P wave 202, QRS complex 210, and I wave 220. Some representations can in addition include a U wave (not shown). The P wave can represent normal atrial depolarization, when the main electrical vector spreads from the right atrium to the left atrium. The shape and duration of the P wave can be related to the size of the user's atrium (e.g., indicating atrial enlargement), and can be a first source of heartbeat characteristics unique to a user.

The QRS complex can correspond to the depolarization of the heart ventricles, and can be separated into three distinct waves—a Q wave, a R wave and a S wave. Because the ventricles contain more muscle mass than the atria, the QRS complex is larger than the P wave. In addition, the His/Purkinje system of the heart, which can increase the con-



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duction velocity to coordinate the depolarization of the ventricles, can cause the QRS complex to look “spiked” rather than rounded. The duration of the QRS complex of a healthy heart can be in the range of 60 to 100 ms, but can vary due to abnormalities of conduction. The duration of the QRS complex can therefore serve as a second source of heartbeat characteristics unique to a user.

The duration, amplitude, and morphology of each of the Q, R and S waves can vary in different individuals, and in particular can vary significantly for users having cardiac diseases or cardiac irregularities. For example, a Q wave that is greater than  $\frac{1}{3}$  of the height of the R wave, or greater than 40 ms in duration can be indicative of a myocardial infarction and provide a unique characteristic of the user’s heart. Similarly, other healthy ratios of Q and R waves can be used to distinguish different users’ heartbeats.

Representation 200 may include one or more characteristic durations or intervals that can be used to distinguish different users. For example, representation 200 can include PR interval 204 and ST segment 212. PR interval 204 can be measured from the beginning of P wave 202 to the beginning of QRS complex 210. PR interval 204 can typically last 120 to 200 ms. A PR interval 204 having a different duration can indicate one or more defects in the heart, such as a first degree heart block (e.g., PR interval 204 lasting more than 200 ms), a pre-excitation syndrome via an accessory pathway that leads to early activation of the ventricles (e.g., PR interval 204 lasts less than 120 ms), or another type of heart block (e.g., PR interval 204 is variable). ST segment 212 can be measured from QRS complex 210 to T wave 220, for example starting at the junction between QRS complex 210 and ST segment 212 and ending at the beginning of T wave 220. ST segment 212 can typically last from 80 to 120 ms, and normally has a slight upward concavity. The combination of the length of ST segment 212, and the concavity or elevation of ST segment 212 can also be used to generate characteristic information unique to each user’s heartbeat.

T wave 220 can represent the repolarization or recovery of the ventricles. The interval from the beginning of the QRS complex to the apex of the T wave can be referred to as the absolute refractory period. The last half of the T wave can be referred to as the relative refractory period or vulnerable period. The amplitude of T wave 220, the duration of the absolute refractory period, and the relative refractory period can also be used to define a characteristic of the user’s heart rate.

QT interval 222, which can represent the total time needed for the ventricles to depolarize and repolarize, can be measured from the beginning of QRS complex 210 to the end of T wave 220. QT interval 222 can typically last between 300 and 450 ms, and can vary based on the condition of the user’s heart rate. Several correction factors have been developed to correct QT interval 222 for the heart rate. Both the measured and corrected QT interval 222 values can be used to define a unique characteristic of a user’s heartbeat.

Because a user’s heartbeat or heart rate can vary slightly based on the user’s activity or mood, each authorized user can initially provide a base or standard heart rate, heartbeat, or electrical activity to the device prior to first use. For example, the electronic device can sample several heartbeats or electrical activity at several different times to detect variations in the user’s cardiac electrical activity. The electronic device can process detected signals to determine several unique characteristics of the user’s heart activity, and identify a range of suitable characteristic values for each of the processed characteristics. Based on the characteristic

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values and associated ranges, the electronic device can select one, all or a subset of the characteristics to define a unique heart activity profile for the authorized user. The particular combination of characteristics and associated ranges can be selected to minimize overlap with other authorized users, or based on characteristic values and ranges that do not fall within a range of average values and ranges (e.g., do not use characteristic values and ranges that an average user of the device would have).

The heart sensor of the electronic device can include several leads for detecting the user’s heart activity. The leads can be integrated in any suitable portion of the electronic device. FIG. 3 is a schematic view of an illustrative electronic device having several integrated leads in accordance with one embodiment of the invention. Electronic device 300 can include display 302 and bezel 310, and be portable such that a user can hold electronic device with fingers extending against one of sides 312 and 314 of bezel 310, and the user’s thumb extending against the other of sides 312 and 314. Leads 322 and 324, which can include conductive pads, can be coupled to sides 312 and 314 of bezel 310, respectively, such that when the user holds the device, the user’s thumb and fingers are placed in contact with leads 322 and 324. Alternatively, bezel 310 can include any other suitable number of leads, or any other suitable distribution of leads along bezel 310 and in other portions of electronic device 300. The leads can detect the user’s cardiac activity through the contact with the user’s thumb and fingers, and provide the detected activity to the electronic device processor for processing. The size of leads 322 and 324 can be selected based on any suitable consideration, including for example the different possible positions of a user’s hands on the device, the amount of contact necessary to detect the user’s cardiac activity, preventing or reducing short circuits and other cardiac signal detection errors, manufacturing considerations (e.g., the minimum or maximum size leads that can be integrated in the bezel), aesthetic considerations (e.g., sizing leads 322 and 324 to reduce the visibility of leads 322 and 324), or any other suitable consideration.

In some embodiments, electronic device 300 can include additional lead 326 embedded in or behind display 302. Lead 326 can be operative to detect a user’s heart activity as the user moves a finger across display 302, for example in the vicinity of or directly over lead 326 (e.g., as the user drags a finger over lead 326 to move a slider when unlocking the electronic device). Using lead 326, the electronic device can detect an electrical signal from a different portion of the user’s body (e.g., leads 322 and 324 detect signals through a first hand, and lead 326 detects signals through the second hand), which can provide the processor with additional information for determining characteristics of the user’s cardiac activity.

Any suitable approach can be used to prevent leads 322, 324 and 326 from shorting. In particular, electronic device 300 can include at least one non-conductive component positioned between each of leads 322, 324 and 326. For example, a rubber gasket can be positioned between leads 322 and 324 (in bezel 310) and lead 326 (in display 302). In some embodiments, the cardiac electrical signals detected by leads 322, 324 and 326 can be faint or have particular characteristics that require materials having particular properties (e.g., silver-based compounds) to detect and transmit. In such cases, although the material used for bezel 310 or other electronic device components can be conductive, its conductivity can be insufficient to transmit signals detected by lead 322 directly to lead 324 (e.g., shorting leads 322 and 324). This may allow leads 322 and 324 to be embedded

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directly in bezel 310 without the need for additional isolating material, which can add cost and complexity to the manufacturing process.

To ensure that electronic device 300, and in particular bezel 310 remains aesthetically pleasing, leads 322 and 324 can be finished to resemble bezel 310. For example, leads 322 and 324 can be polished or roughened to match the finish of bezel 310. As another example, a conductive coating can be applied to leads 322 and 324 to match the color, tone and reflectivity of bezel 310. In some embodiments, the texture or feel of leads 322 and 324 can also be selected to render leads 322 and 324 visibly and haptically indistinguishable or nearly indistinguishable from bezel 310.

Leads 322 and 324 can be integrated in bezel 310 using any suitable approach. In some embodiments, leads 322 and 324 can be positioned on the exterior surface of bezel 310 and include an electrically conductive path to the electronic device processor. FIG. 4A is a cross-sectional view of an illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention. Electronic device 400 can include display 402 and bezel 410. Lead 422 can be embedded along the outer surface of bezel 410 such that lead 422 is exposed to the user during use. Connector 424 can be coupled to the inner surface of lead 422 and extend into electronic device 400 to be coupled with a processor. In some embodiments, electronic device 400 can in addition include an isolating layer positioned between lead 422 and bezel 410 (not shown). The isolating layer can be constructed from any suitable material having non-conductive properties, including for example a ceramic material, plastic, rubber, or any other suitable material. Alternatively, if the material of bezel 410 is not conductive, or insufficiently conductive to cause several distinct leads 422 positioned on bezel 410 from shorting, no isolating layer may be necessary.

FIG. 4B is a cross-sectional view of another illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention. Electronic device 450 can include display 452 and bezel 460. If the electrical conductivity and size of bezel 460, and the strength or characteristics of the cardiac signal provided by the user and detected by the heart sensor are adapted such that the signal can be transmitted along short distances in bezel 460, lead 472 of the heart sensor can be positioned against the back surface of bezel 460. Alternatively, lead 472 can be placed within the thickness of bezel 460 (e.g., in a pocket within the bezel wall), but underneath the outer surface of the bezel. The short thickness of bezel 460 can allow electrical signals to propagate from the user to the outer surface of bezel 460, through bezel 460, and into lead 472, which may in turn transmit the signals to a processor using connector 474. In addition, if several leads are placed along different portions of bezel 460, the distance between adjacent leads can be sufficiently large (e.g., substantially larger than the thickness of bezel 460) that different leads of bezel 460 cannot detect the same electrical signal.

In some embodiments, entire portions of the bezel can be used as leads for the heart sensor. FIG. 5 is a schematic view of an illustrative electronic device using portions of the bezel as leads in accordance with one embodiment of the invention. Similar to electronic device 300 (FIG. 3), electronic device 500 can include display 502 and bezel 510. Bezel 510 can be separated into several electrically isolated segments, for example segments 522 and 524. The segments can be electrically isolated using isolating portions 530 and 532, which can be constructed from any suitable non-

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conductive material, such as for example a composite material, a plastic, rubber, or any other suitable material. Although FIG. 5 shows bezel 510 broken into two segments having similar sizes, it will be understood that bezel 510 can be separated into any suitable number of electrically isolated segments, and each segment can have any suitable size. In particular, the sizes and distribution of each segment can be selected based on physiological considerations (e.g., where a user's hand will be positioned on the device, or aligning the segments to contact particular portions of the user's body).

To ensure that electronic device 500 remains aesthetically pleasing, isolating portions 530 and 532 can be finished to resemble bezel 510. For example, isolating portions 530 and 532 can be polished or machined to create a reflective surface matching the reflection of bezel 510. As another example, a reflective or finishing coating can be applied to the surfaces of isolating portions 530 and 532 to match the finish of bezel 510. In some embodiments, the texture of isolating portions 530 and 532 can also be selected to render segments 522 and 524 visually and haptically indistinguishable or nearly indistinguishable from isolating portions 530 and 532.

Other heart sensor leads can be placed at any other suitable position on the electronic device enclosure. For example, if the enclosure is constructed from a bezel supporting a display and a housing forming the exterior surface of the device behind the display, one or more leads can be embedded in or adjacent to the housing. For example, if the housing includes a conductive section (e.g., a plastic housing with a metallic logo in the center of the housing), the lead can be coupled to or integrated in the conductive section.

The heart sensor and processor can detect and process the user's cardiac activity at any suitable time. For example, the processor can receive and process heart activity when the device is locked and held while in its locked state. As another example, the processor can receive and process heart activity as the user places a finger over lead 326 (e.g., when the user slides a finger across the display to unlock the device) or when an input mechanism detects a particular input. As still another example, the electronic device can receive and process heart activity data in response to a user instruction or request to access a particular application or data that for which access is restricted. Upon receiving the cardiac activity, the electronic device can extract one or more characteristics of the received activity and compare the extracted characteristics with the characteristics previously stored in memory that were associated with authorized users. If the extracted characteristics match those of an authorized user, the electronic device can authenticate the identified user.

The electronic device can perform any suitable operation in response to identifying and authenticating a user based on detected cardiac signals. In some embodiments, the electronic device can provide access to restricted applications, for example applications for which only particular users have licenses or that only particular users have purchased. In some embodiments, the electronic device can provide access to particular data or application settings associated with an authorized user. For example, the electronic device can provide access to the identified user's contact list, or to the identified user's e-mail account or telephone history. As another example, the electronic device can allow the user to access private banking applications, or conduct financial transactions (e.g., transferring funds to different accounts, or purchasing merchandise) using the electronic device. In



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some embodiments, the electronic device can load user settings and profiles for providing a customized display to the user. For example, the electronic device can display icons or options in the manner set by the user, or provide displays using a color scheme, fonts, or other customizable display attribute that are associated with the identified user.

In some embodiments, the electronic device can use the detected heart rate or heartbeat characteristics to determine the user's mood. In particular, because the allowable determined characteristics associated with each user can include a range of values, the electronic device can determine the distribution of the detected characteristics in the allowable characteristic ranges. Using the determined distribution, the electronic device can establish a user's mood and provide electronic device operations or data (e.g., media) associated with the extrapolated mood. Systems and methods for providing mood-based electronic device operations are discussed in more detail in commonly assigned U.S. Publication No. 2010/0011388, which is incorporated by reference herein in its entirety.

In some embodiments, the electronic device can provide media playback based on the user's detected cardiac signal. For example, the electronic device can identify media having beats per minute or other characteristics that are associated with or related to the user's cardiac signal or heart rate, and play back the identified media. As another example, the media provided can have beats per minute faster or slower than the user's current heart rate to direct the user to work harder (e.g., during a workout) or to cool or calm the user down (e.g., at the end of a workout).

FIG. 6 is a flowchart of an illustrative process for performing an electronic device operation based on a user's cardiac signal in accordance with one embodiment of the invention. Process 600 can begin at step 602. At step 604, the electronic device can detect a user's cardiac signal. For example, the electronic device can detect a user's heart rate or heart beat using one or more leads connected to or placed on a housing, bezel, or other exterior surface of the electronic device. The electronic device can process the received signal using any suitable approach, including for example to determine unique characteristics of the signal. Such characteristics can include, for example, durations between peaks in an EKG signal, peak values or ratios between peaks in the EKG signal, or any other suitable characteristic. At step 606, the electronic device can determine whether the user detected at step 604 is an authorized user. For example, the electronic device can compare the determined characteristics of the detected cardiac signals with a library of signals associate with known authorized users. If the electronic device determines that the user is not authorized (e.g., the characteristics of the detected cardiac signal do not match characteristics of a cardiac signal stored in memory), process 600 can move to step 608.

At step 608, the electronic device can prevent access to restricted electronic device operations. For example, the electronic device can prevent the user from accessing personal or private information associated with other users. As another example, the electronic device can prevent the user from accessing applications or operations associated with particular users (e.g., applications purchased by particular users). As still another example, the electronic device can prevent the user from accessing any electronic device operation (e.g., no operation except for emergency calls). Process 600 can then end at step 610.

If, at step 606, the electronic device instead determines that the user is authorized, process 600 can move to step 612. At step 612, the electronic device can determine the

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restricted operations that are associated with the user. For example, the electronic device can determine the particular private data associated with the authorized user (e.g., e-mail accounts, contact lists and banking information). As another example, the electronic device can determine the particular operations or applications associated with the authorized user (e.g., applications purchased by the user using an applications store, or system controlling operations associated with an administrative account). At step 614, the electronic device can provide access to the user's determined restricted operations. For example, the electronic device can load determined data. As another example, the electronic device can provide links for launching determined personal or private applications. Process 600 can then end at step 610.

The above-described embodiments of the present invention are presented for purposes of illustration and not of limitation, and the present invention is limited only by the claims which follow.

What is claimed is:

1. An electronic device for detecting a user's cardiac signal, comprising:
  - an enclosure;
  - a heart sensor configured to detect the user's cardiac signal, the heart sensor comprising:
    - a first lead comprising a first pad that is embedded in a first portion of the enclosure, wherein an exterior surface of the enclosure comprises an exterior surface of the first portion, wherein the first pad is positioned underneath the exterior surface of the first portion, and wherein the first pad is configured to detect a first electrical signal of the user's cardiac signal via the user's skin's contact with the exterior surface of the first portion of the enclosure; and
    - a second lead comprising a second pad that is embedded in a second portion of the enclosure, wherein the second pad is configured to detect a second electrical signal of the user's cardiac signal via the user's skin's contact with at least one of the second pad and the second portion of the enclosure; and
  - a processor coupled to the heart sensor and configured to receive and process the detected cardiac signal, wherein the first lead further comprises a first connector coupled to the first pad and configured to provide the first electrical signal detected by the first pad to the processor, and wherein the second lead further comprises a second connector coupled to the second pad and configured to provide the second electrical signal detected by the second pad to the processor.
2. The electronic device of claim 1, wherein the first portion and the second portion are located on opposite sides of the electronic device.
3. The electronic device of claim 1, wherein the first portion is electrically isolated from the second portion.
4. The electronic device of claim 1, wherein:
  - the first portion is separated from the second portion by a third portion of the enclosure;
  - at least the third portion is constructed from a material having a first conductivity; and
  - the first conductivity is insufficient to transmit the first electrical signal from the first pad to the second pad via the third portion.
5. The electronic device of claim 4, wherein:
  - the material having the first conductivity comprises one of aluminum and steel; and
  - the second pad is constructed from a silver based compound.

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6. The electronic device of claim 4, wherein:  
the exterior surface of the enclosure further comprises an  
exterior surface of the second portion;  
the second pad is configured to detect the second electrical  
signal of the user's cardiac signal via the user's  
contact with the exterior surface of the second portion; 5  
the second pad is positioned from the exterior surface of  
the second portion by a thickness of the second portion;  
at least the thickness of the second portion is constructed  
from material having a second conductivity; and 10  
the second conductivity is defined such that the second  
electrical signal is not able to be transmitted through  
material having the second conductivity over a distance  
larger than the thickness of the second portion.

7. The electronic device of claim 6, wherein the first pad 15  
and the second pad are positioned apart from one another at  
a distance larger than the thickness of the second portion by  
material having the second conductivity.

8. The electronic device of claim 1, wherein:  
the enclosure further comprises at least one pocket under- 20  
neath the exterior surface of the enclosure; and  
at least one of the first pad and the second pad is placed  
within the at least one pocket.

9. The electronic device of claim 1, further comprising:  
a display, wherein the enclosure supports the display, and 25  
wherein at least a portion of the exterior surface of the  
enclosure forms at least a portion of an exterior surface  
of the electronic device behind the display; and  
a third lead embedded with the display, wherein the third  
lead is configured to detect a third electrical signal of 30  
the user's cardiac signal via the user's contact with at  
least one of the third lead and the display.

10. The electronic device of claim 1, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the second 35  
portion of the enclosure.

11. The electronic device of claim 1, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the second  
lead. 40

12. The electronic device of claim 1, wherein the first  
portion of the enclosure is a bezel.

13. The electronic device of claim 1, wherein the second  
portion of the enclosure is a bezel.

14. The electronic device of claim 1, wherein an interior 45  
surface of the enclosure comprises an interior surface of the  
first portion, wherein the first pad is positioned on the  
interior surface of the first portion.

15. An electronic device for detecting a user's cardiac  
signal, comprising: 50  
an enclosure;

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a display screen exposed to the user through an opening  
in the enclosure;

a heart sensor configured to detect the user's cardiac  
signal, the heart sensor comprising:  
a first lead embedded in a first portion of the enclosure  
of the electronic device, wherein the first lead is  
configured to detect a first electrical signal of the  
user's cardiac signal via the user's contact with at  
least one of the first lead and the first portion of the  
enclosure of the electronic device; and  
a second lead embedded in the display screen of the  
electronic device, wherein the second lead is con-  
figured to detect a second electrical signal of the  
user's cardiac signal via the user's contact with at  
least one of the second lead and the display screen of  
the electronic device; and  
a processor coupled to the heart sensor and configured to  
process the first and second electrical signals of the  
user's cardiac signal.

16. The electronic device of claim 15, wherein the first  
lead is configured to detect the first electrical signal of the  
user's cardiac signal via the user's contact with the first lead.

17. The electronic device of claim 16, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the second  
lead.

18. The electronic device of claim 16, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the display  
screen.

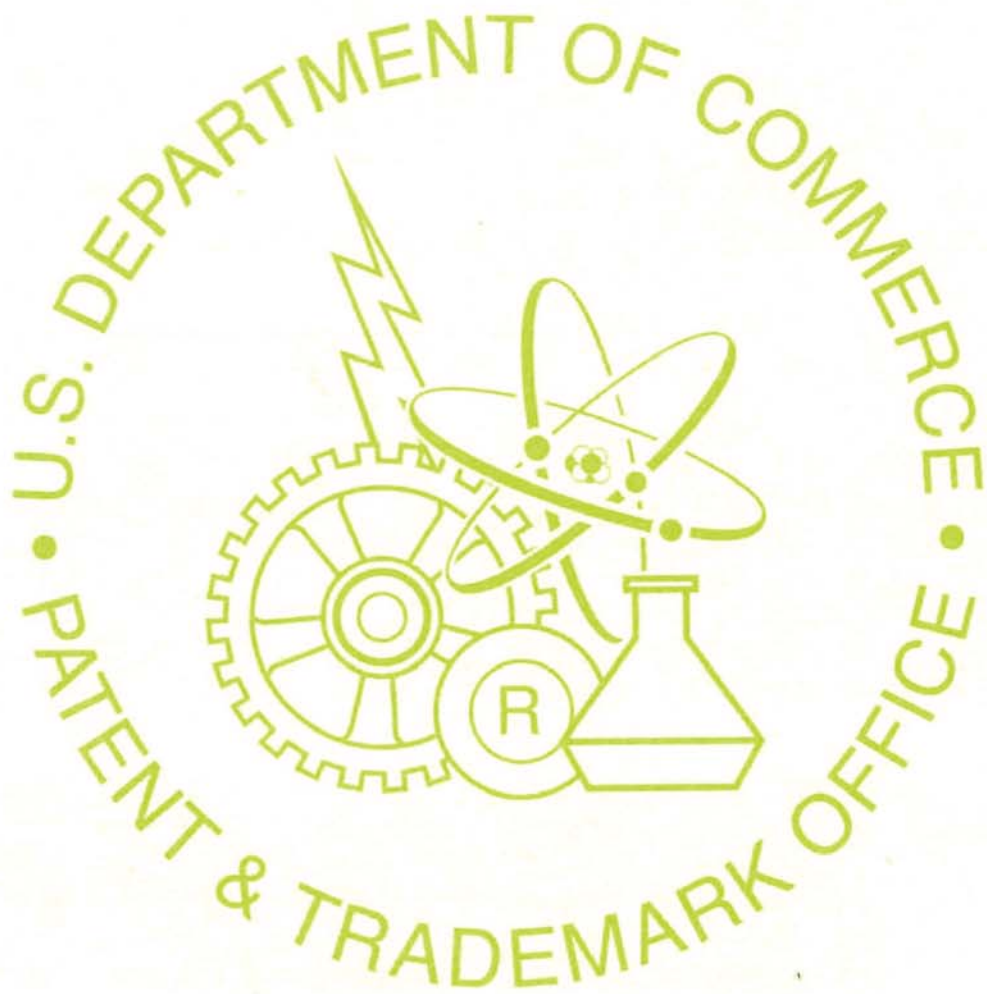
19. The electronic device of claim 15, wherein:  
the first portion of the electronic device comprises a bezel  
of the enclosure;  
the electronic device further comprises a non-conductive  
component positioned between the bezel and the dis-  
play screen for electrically isolating the first lead from  
the second lead.

20. The electronic device of claim 15, wherein the first  
lead is configured to detect the first electrical signal of the  
user's cardiac signal via the user's contact with the first  
portion of the enclosure.

21. The electronic device of claim 20, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the second  
lead.

22. The electronic device of claim 20, wherein the second  
lead is configured to detect the second electrical signal of the  
user's cardiac signal via the user's contact with the display  
screen.

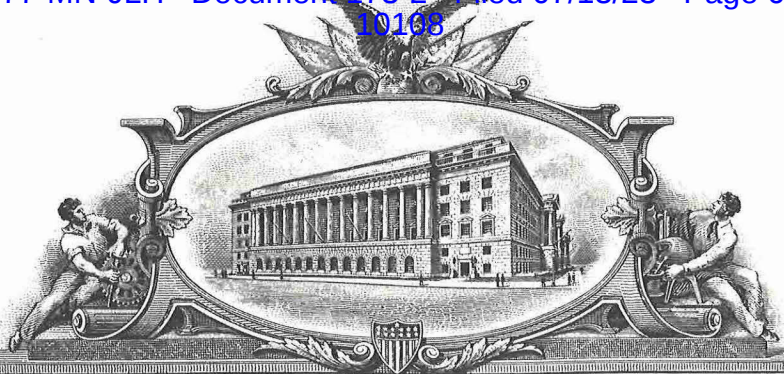
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# **EXHIBIT 6**



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# THE UNITED STATES OF AMERICA

**TO ALL TO WHOM THESE PRESENTS SHALL COME:**

**UNITED STATES DEPARTMENT OF COMMERCE**

**United States Patent and Trademark Office**

January 26, 2023

**THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM  
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**PATENT NUMBER: 10,627,783**

**ISSUE DATE: April 21, 2020**

**By Authority of the  
Under Secretary of Commerce for Intellectual Property  
and Director of the United States Patent and Trademark Office**

*W. Montgomery*  
**Wanda Montgomery**  
**Certifying Officer**





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(12) **United States Patent**  
**Rothkopf et al.**

(10) **Patent No.:** **US 10,627,783 B2**  
(45) **Date of Patent:** **Apr. 21, 2020**

(54) **WEARABLE ELECTRONIC DEVICE**

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**G04G 17/02** (2006.01)  
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CPC ..... **G04G 17/02** (2013.01); **A61B 5/0205** (2013.01); **A61B 5/0261** (2013.01); **A61B 5/0295** (2013.01); **A61B 5/14551** (2013.01); **A61B 5/681** (2013.01); **G04B 39/02** (2013.01); **G04G 21/025** (2013.01); **G06F 1/163** (2013.01);

(Continued)

(58) **Field of Classification Search**

None  
See application file for complete search history.

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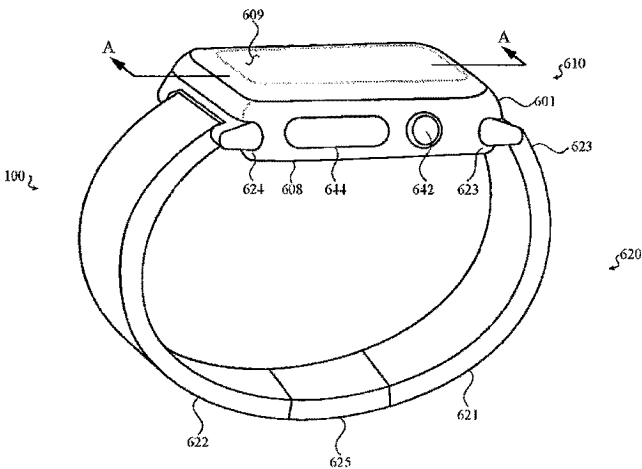
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(57) **ABSTRACT**

A consumer product that is a portable and, in some cases, a wearable electronic device. The wearable electronic device may have functionalities including: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating with other electronic devices or services; visually depicting data on a display; gather data from one or more sensors that may be used to initiate, control, or modify operations of the device; determine a location of a touch on a surface of the device and/or an amount of force exerted on the device, and use either or both as input.

**20 Claims, 26 Drawing Sheets**



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*A61B 5/024* (2006.01)  
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*G04B 3/04* (2006.01)  
*G04G 13/00* (2006.01)

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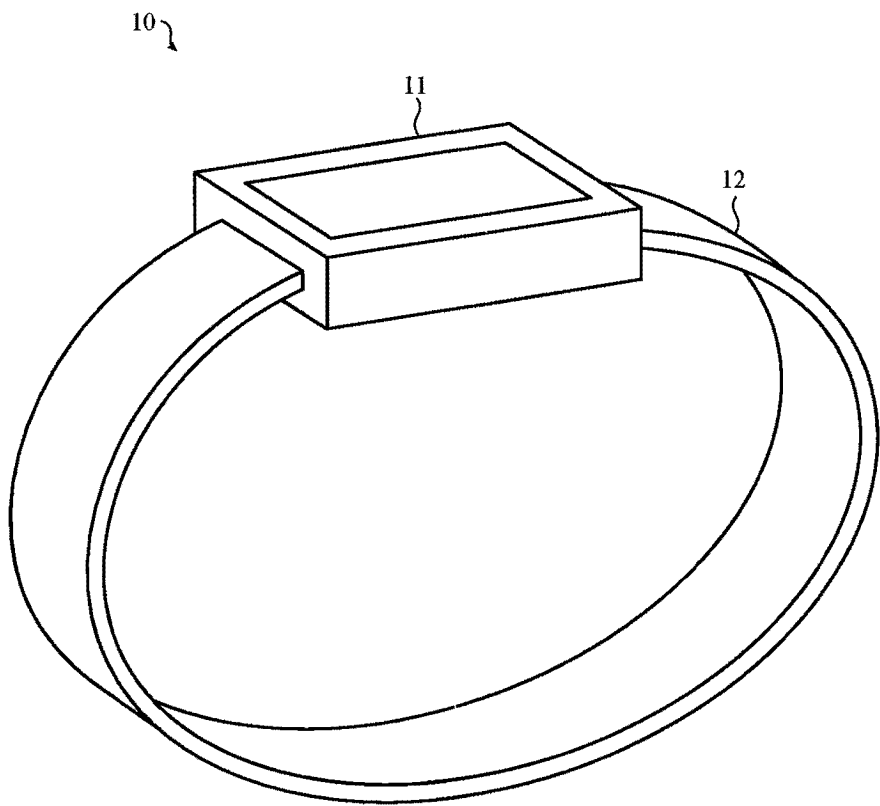


FIG. 1



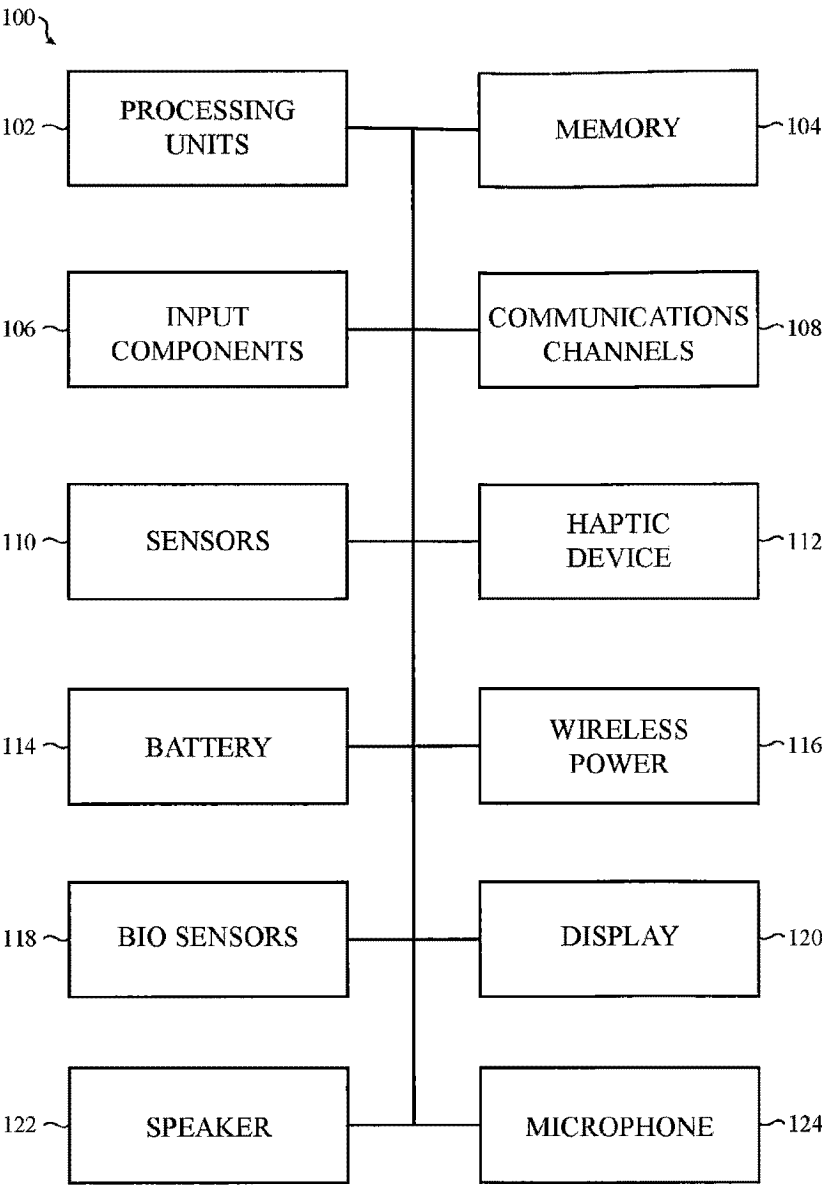


FIG. 2

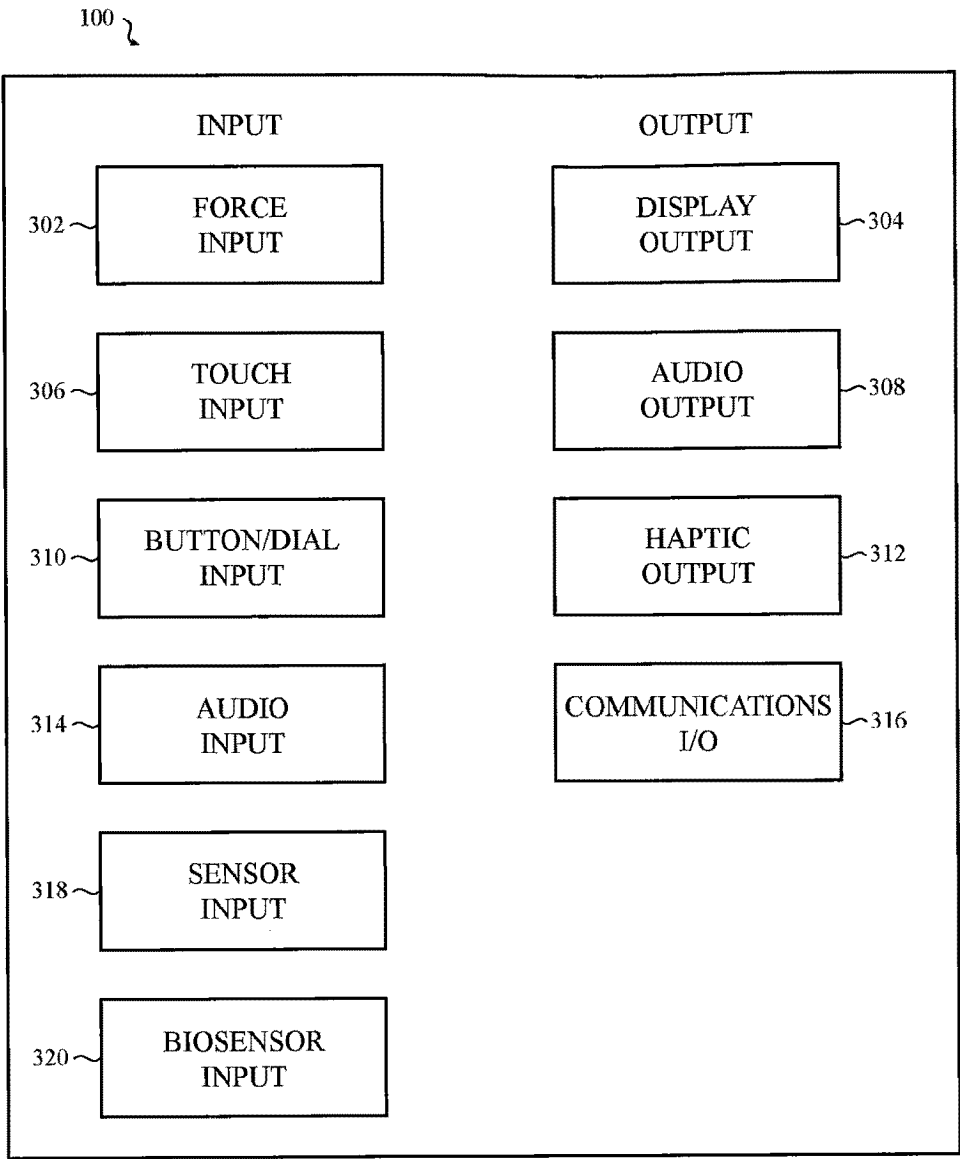


FIG. 3

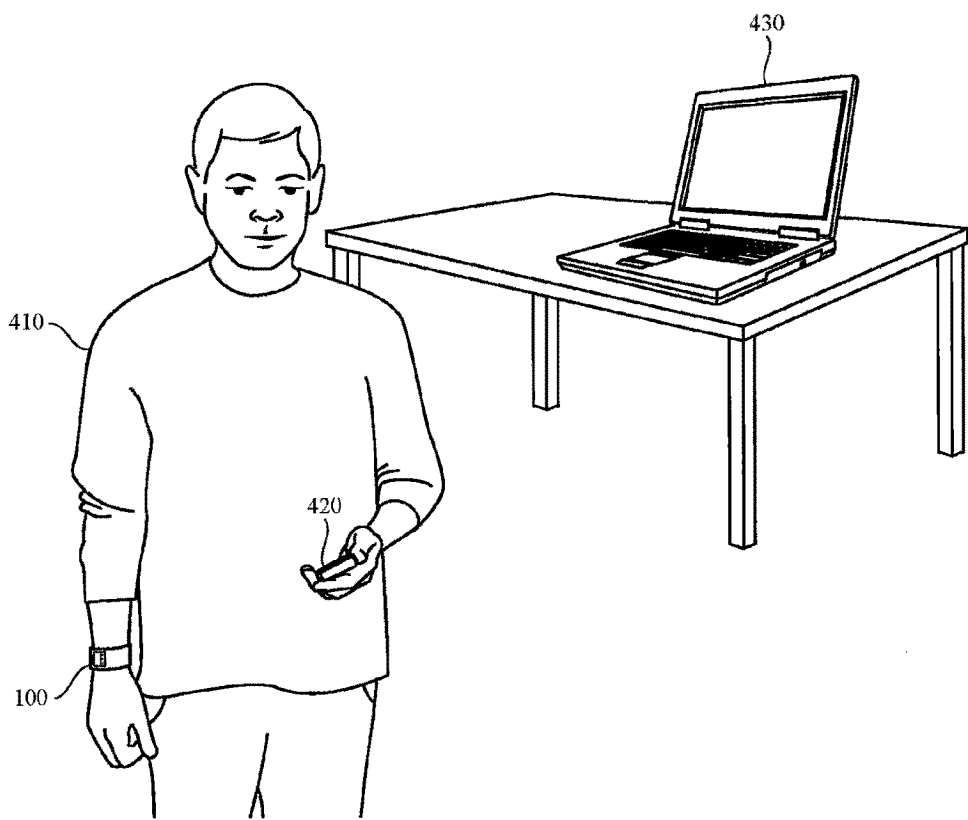
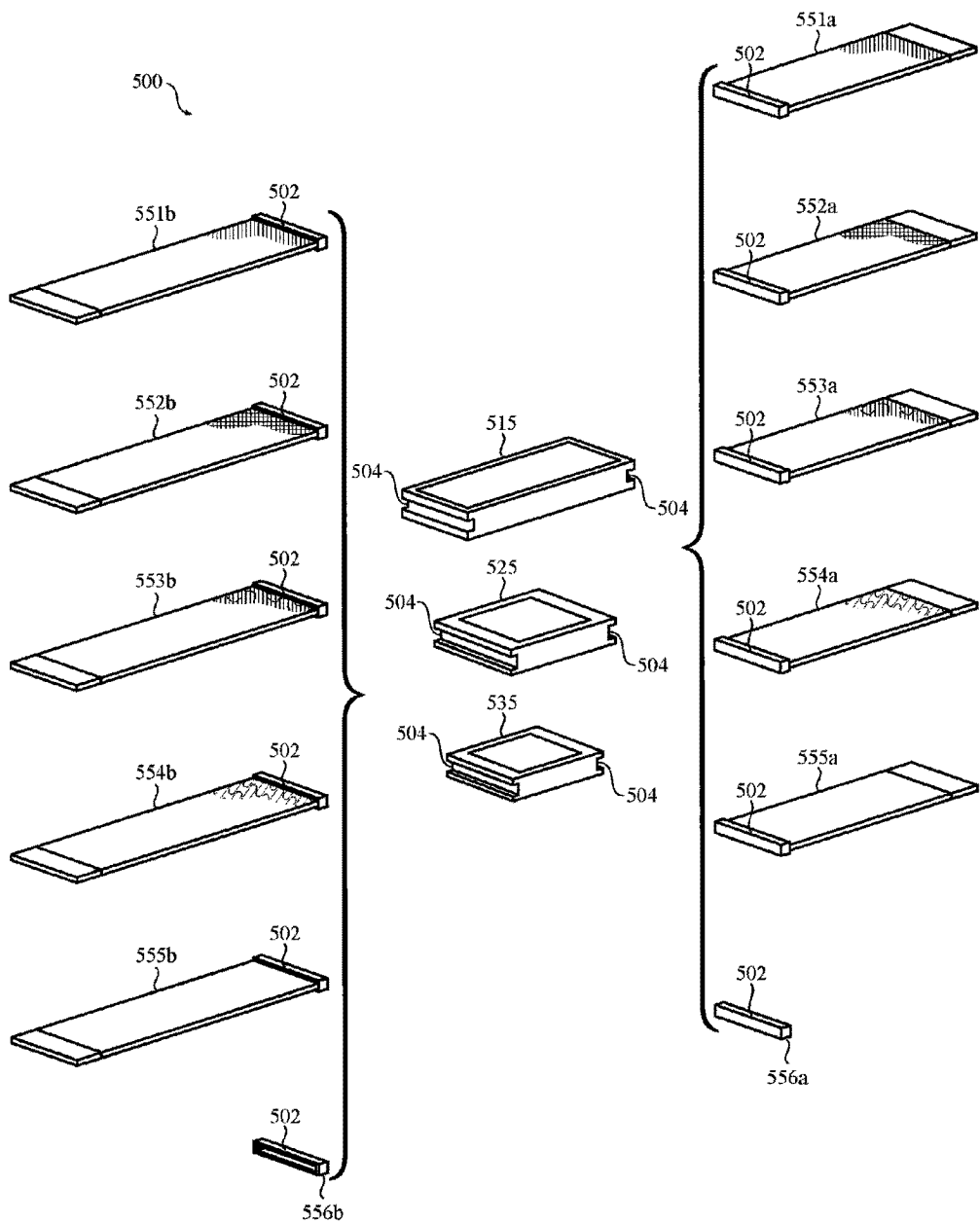


FIG. 4



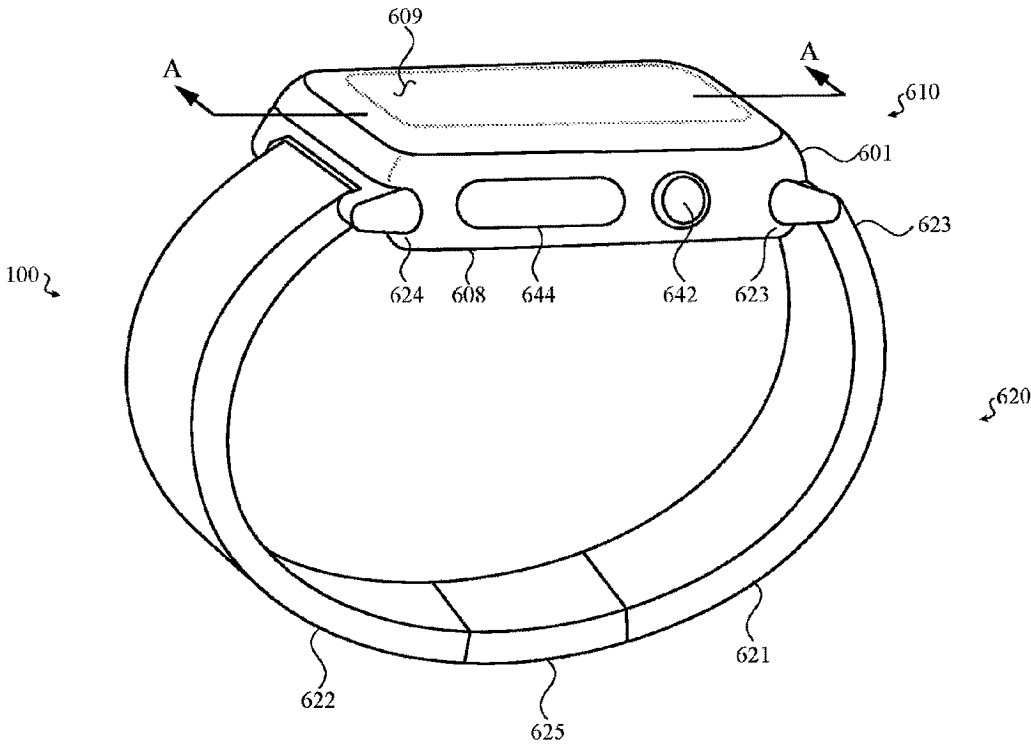


FIG. 6

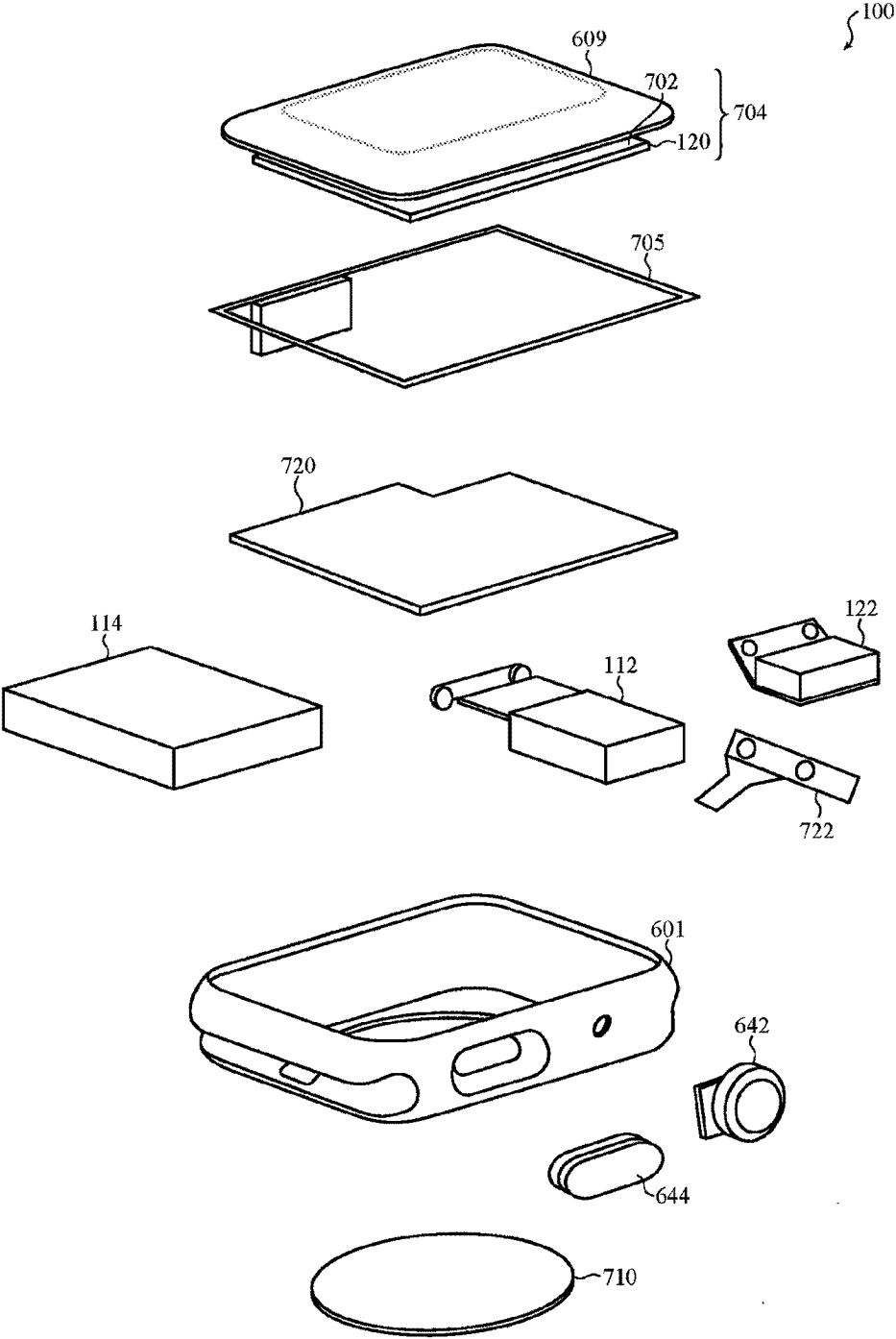


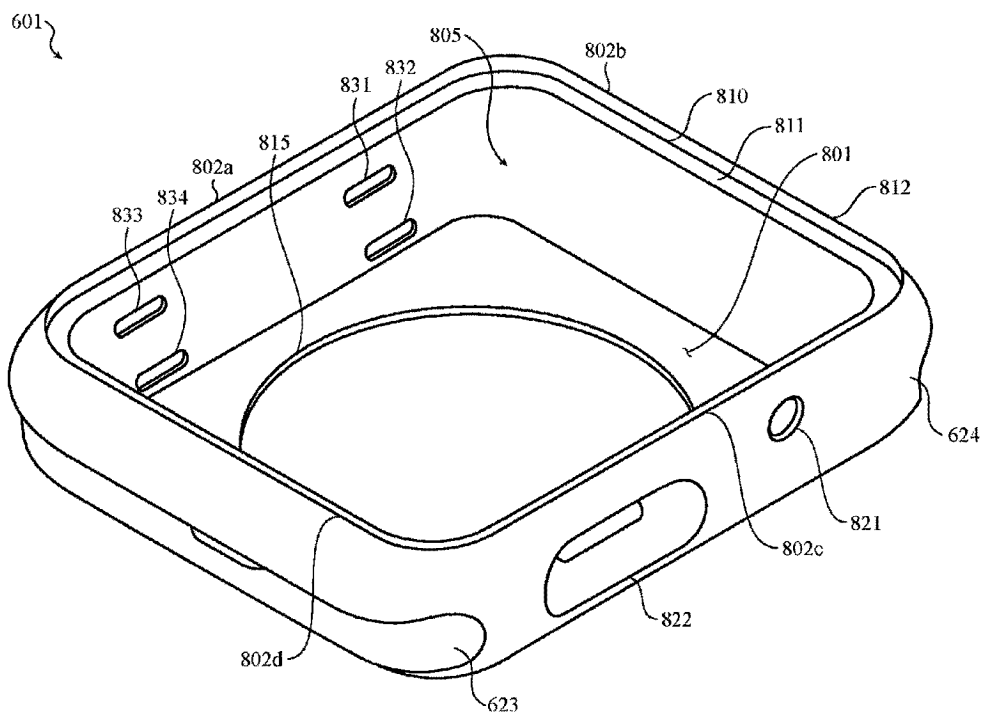
FIG. 7

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**FIG. 8**

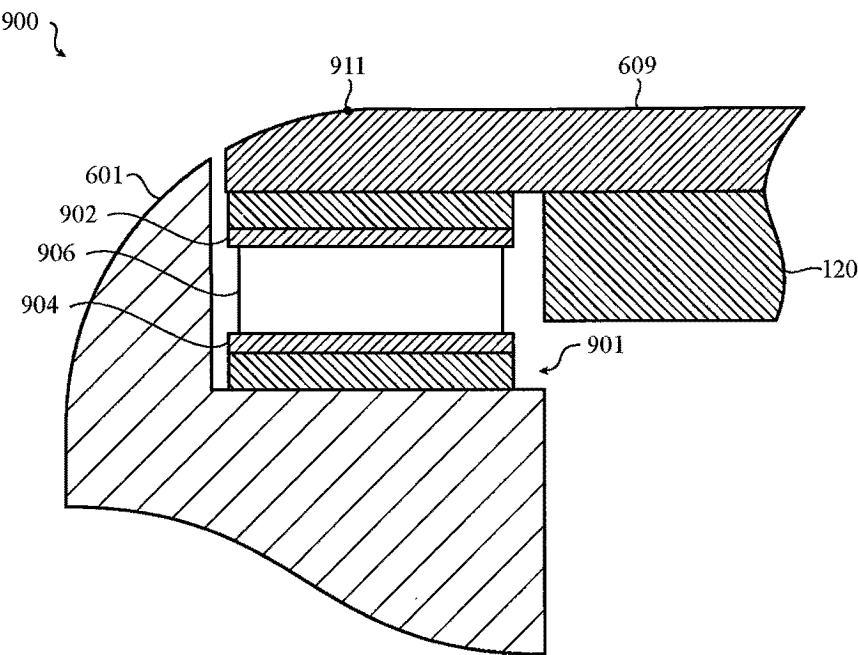


FIG. 9



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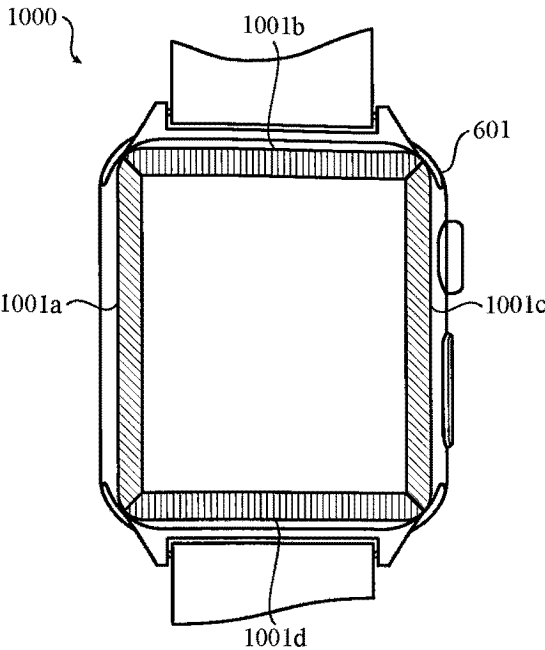


FIG. 10A

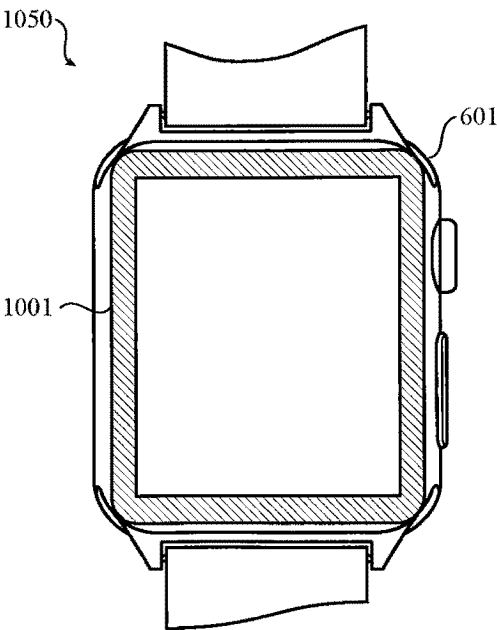


FIG. 10B

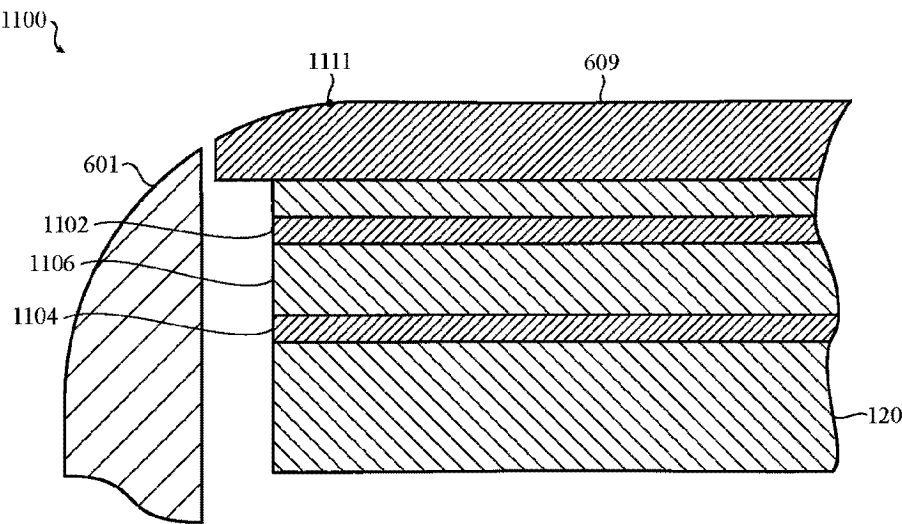


FIG. 11

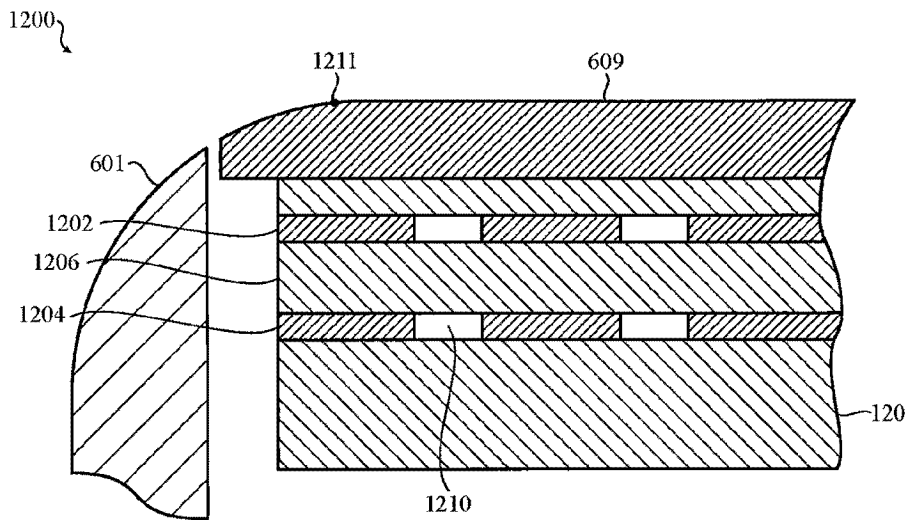


FIG. 12

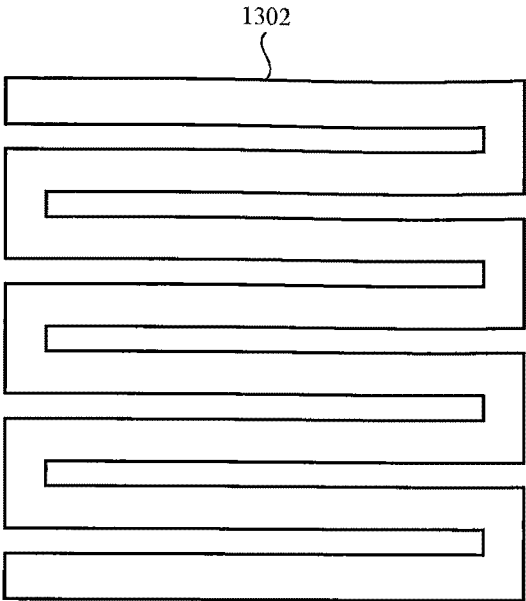


FIG. 13A

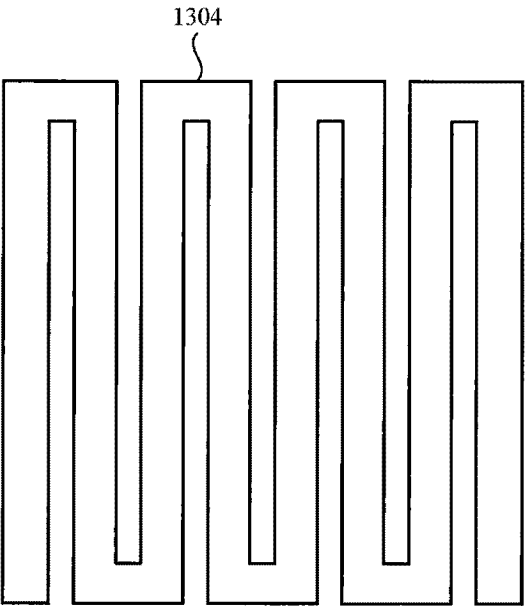


FIG. 13B

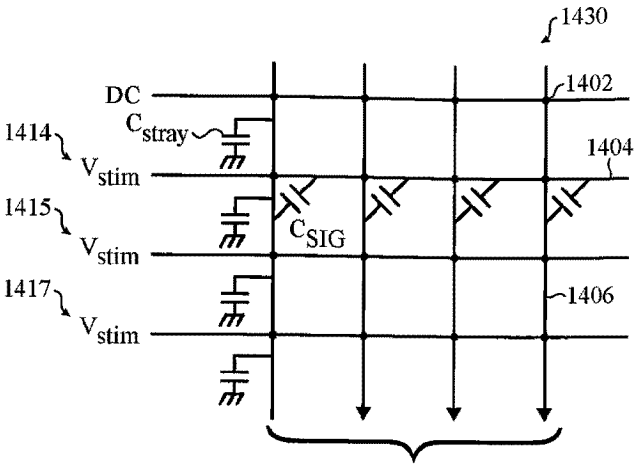


FIG. 14A

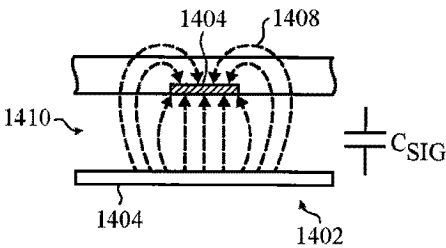


FIG. 14B

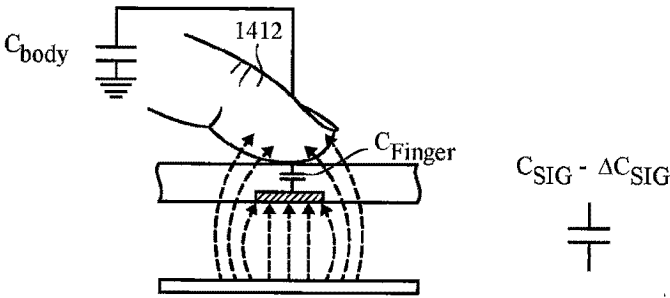


FIG. 14C

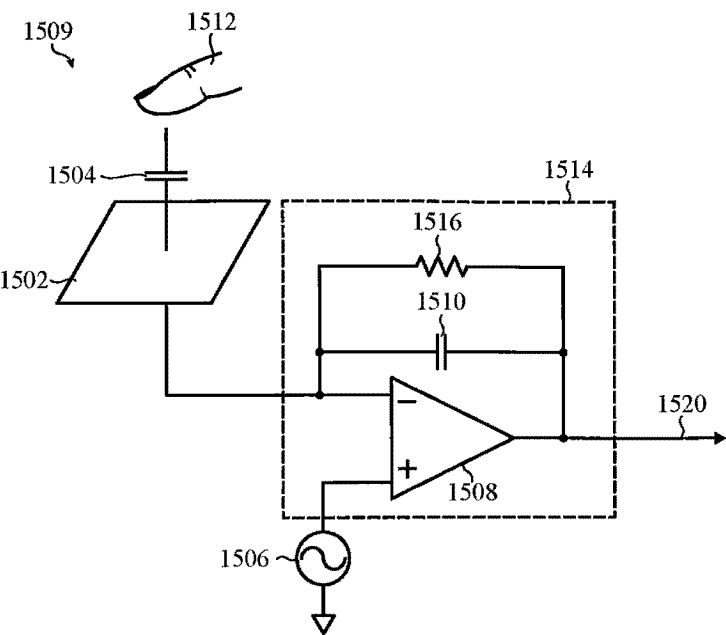


FIG. 15A

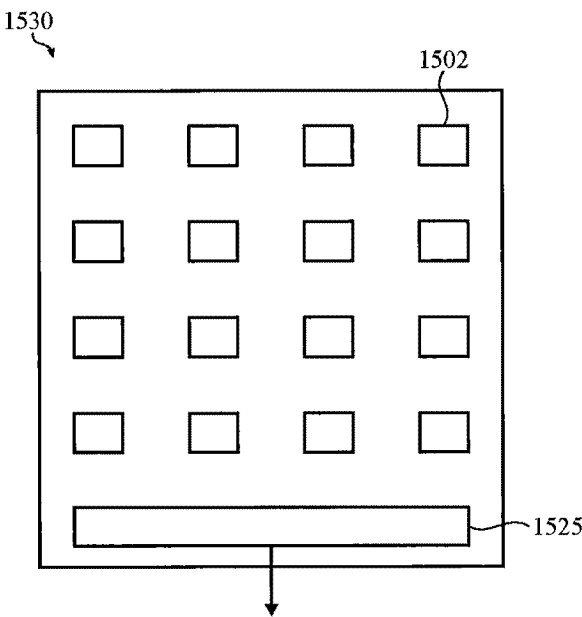


FIG. 15B

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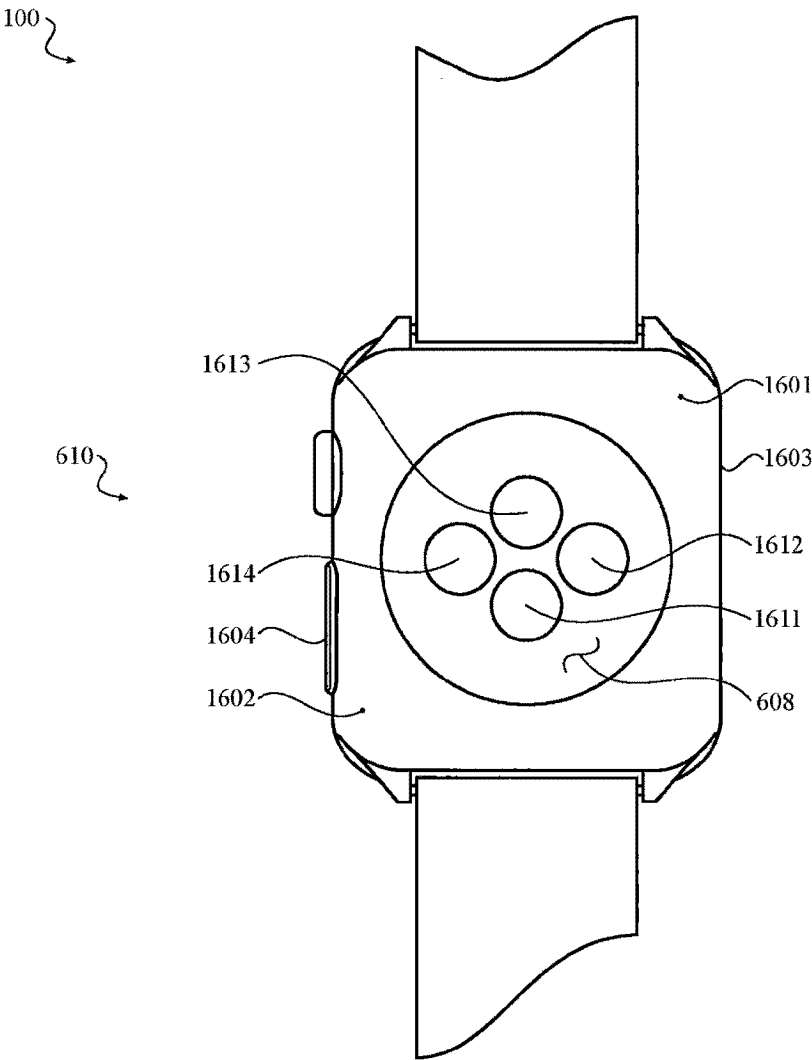


FIG. 16

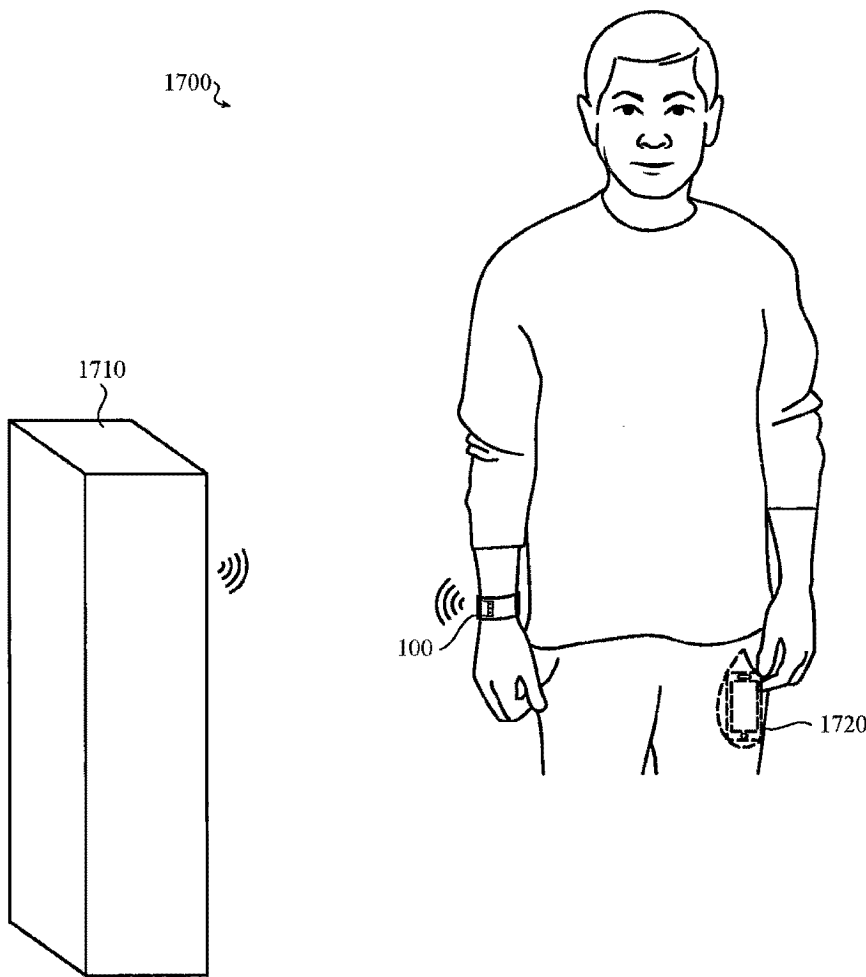


FIG. 17



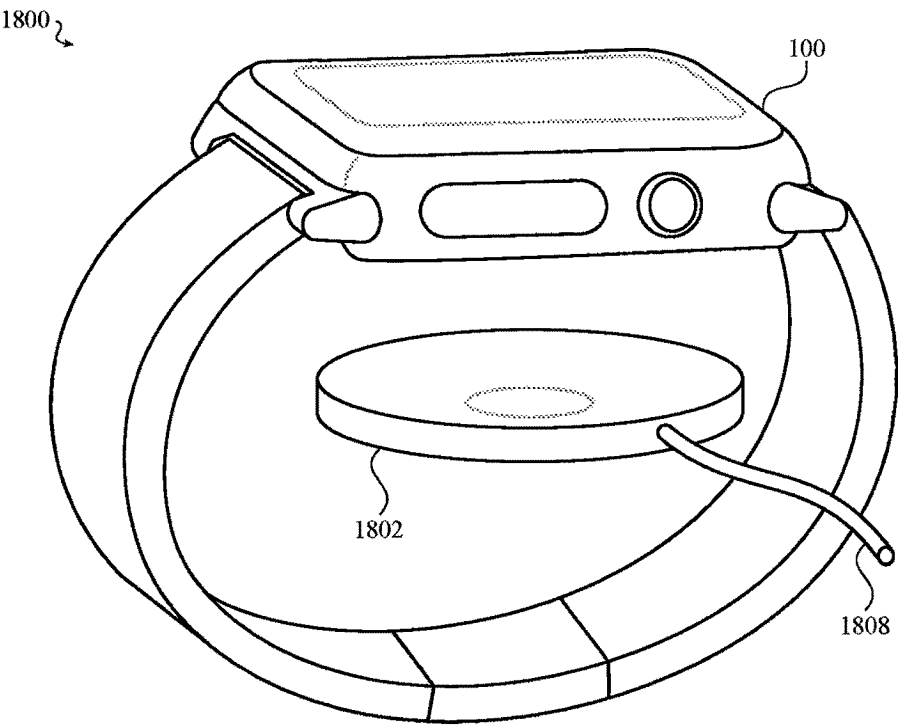


FIG. 18

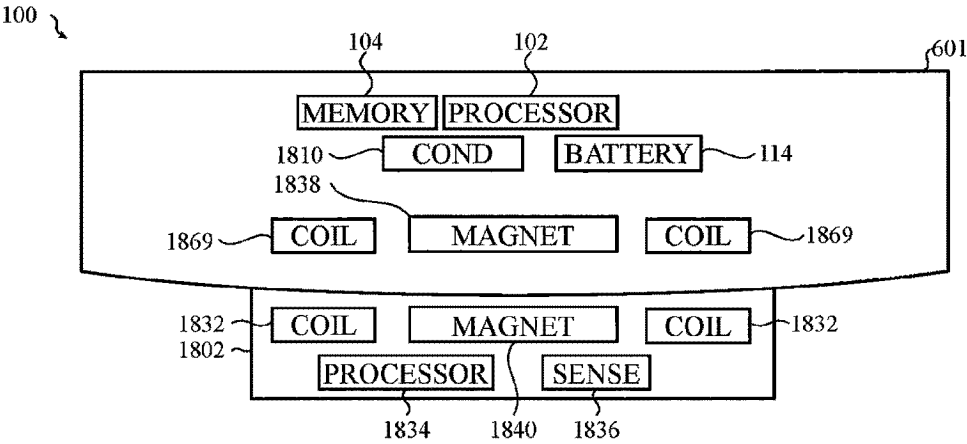


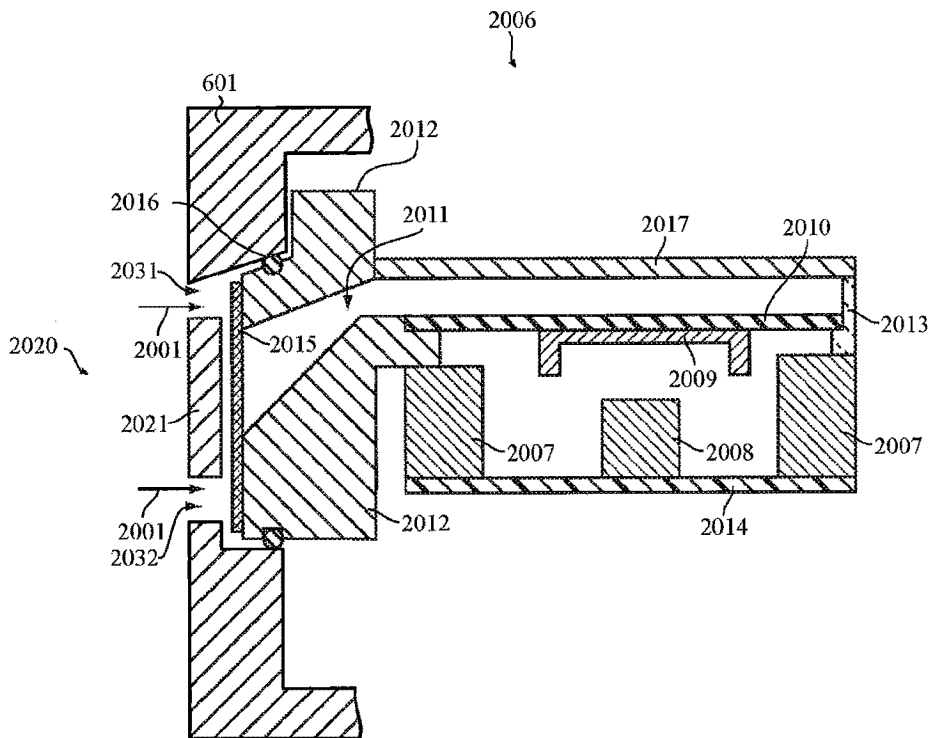
FIG. 19

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**FIG. 20**



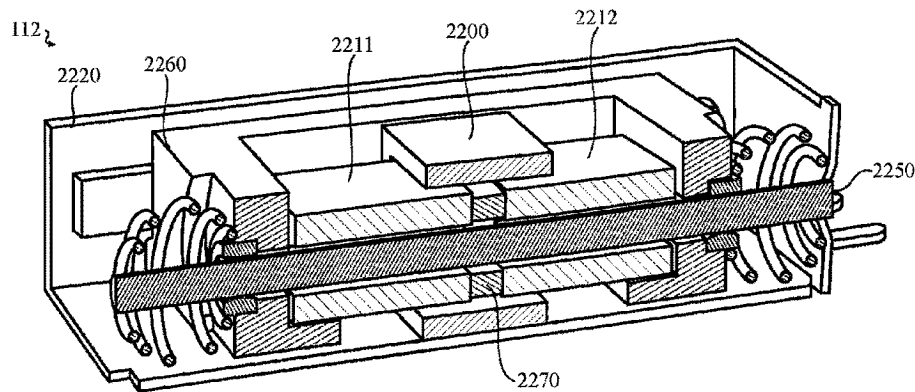


FIG. 22A

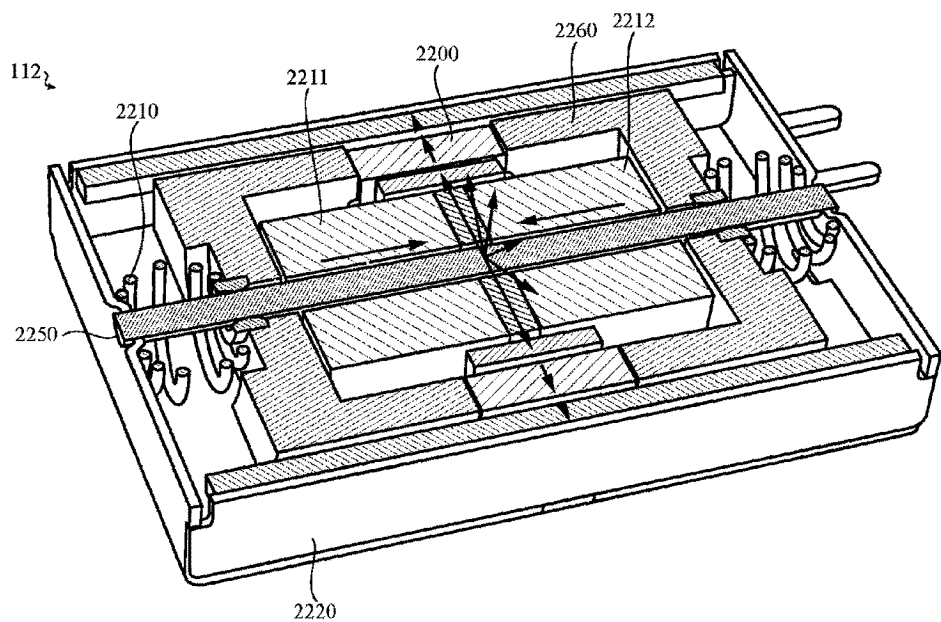


FIG. 22B

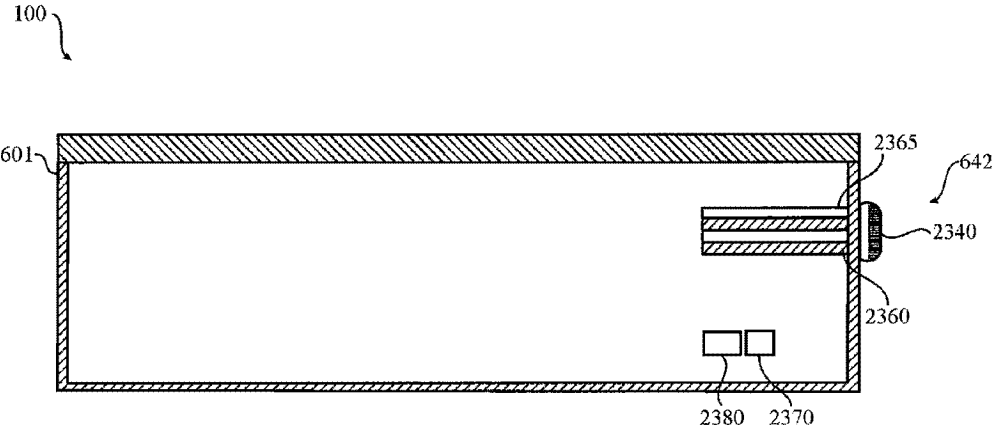


FIG. 23

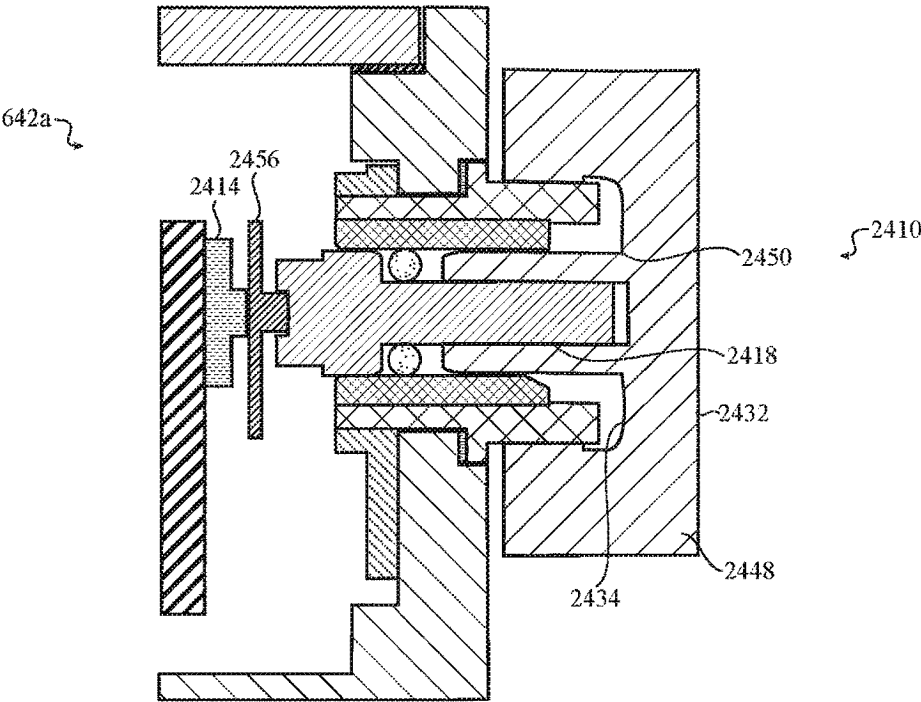


FIG. 24A

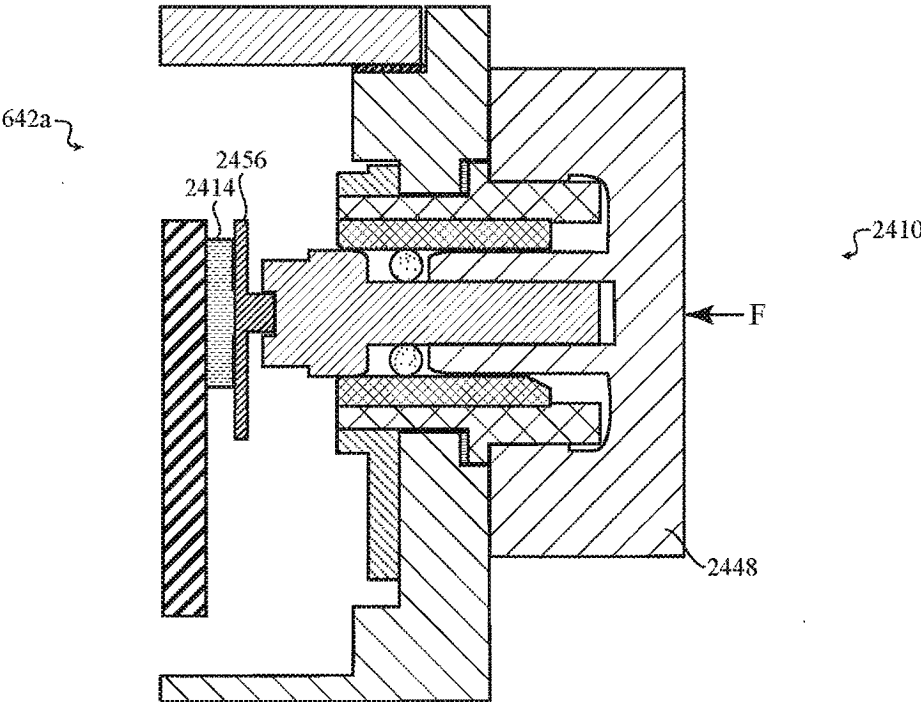


FIG. 24B

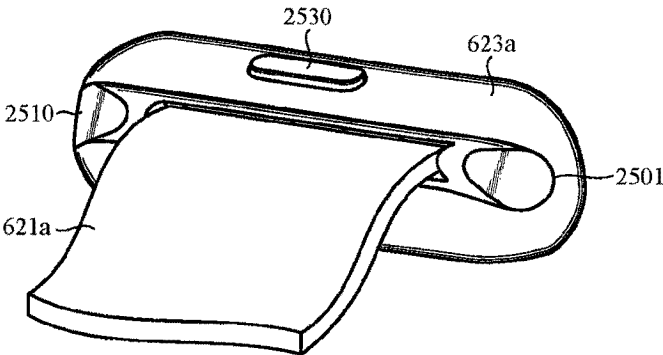


FIG. 25A

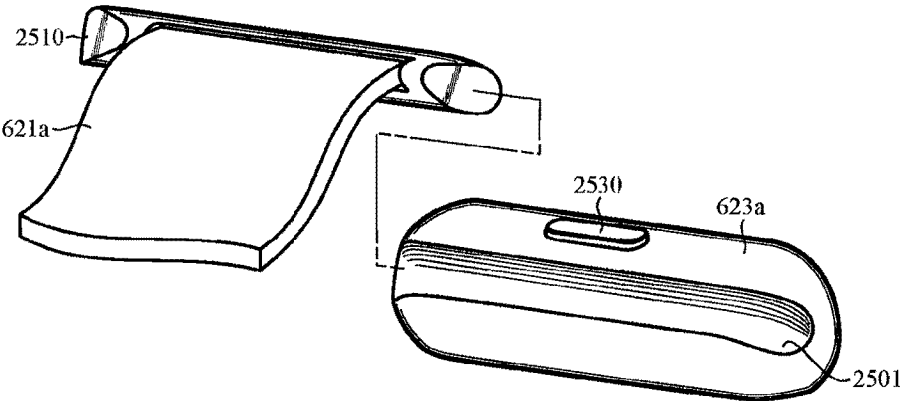


FIG. 25B

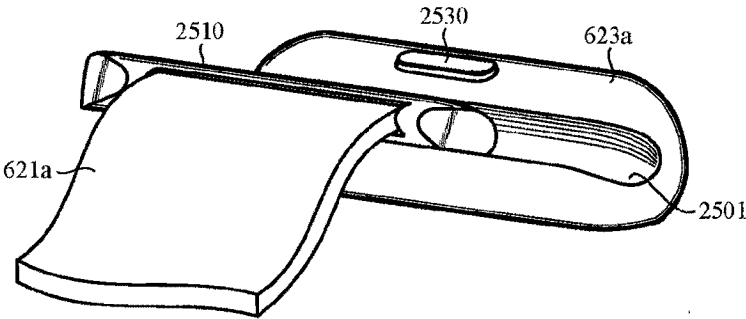


FIG. 25C



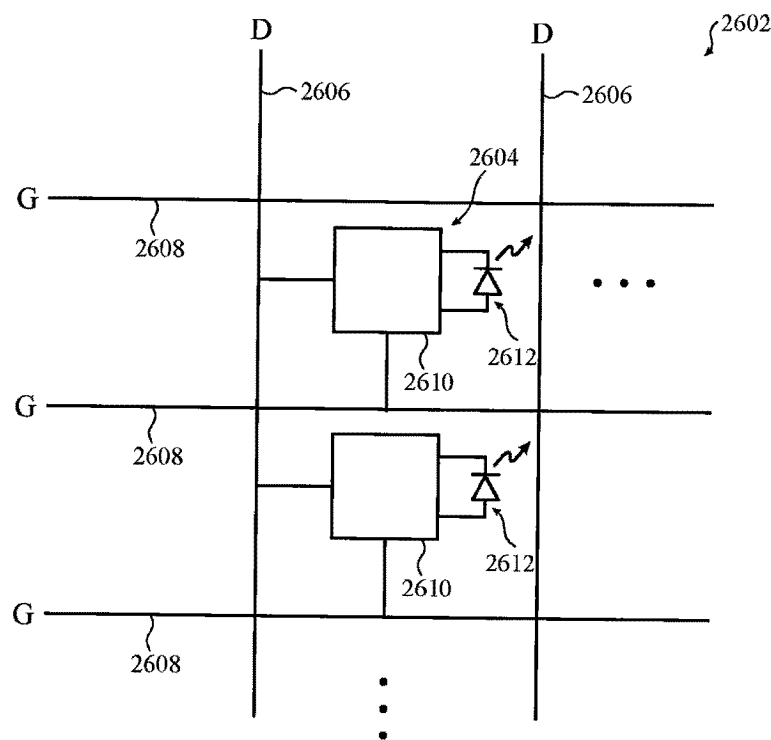


FIG. 26

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# WEARABLE ELECTRONIC DEVICE

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation patent application of U.S. patent application Ser. No. 14/842,617, filed Sep. 1, 2015 and titled "Wearable Electronic Device," which is a nonprovisional patent application of and claims the benefit of U.S. Provisional Patent Application No. 62/044,974, filed Sep. 2, 2014 and titled "Wearable Electronic Device and Associated Methods of Use and Manufacture," the disclosures of which are hereby incorporated herein by reference in their entireties.

## FIELD

The following disclosure generally relates to an electronic device, and more specifically to a wearable electronic device having a range of features, including touch input, force input, an interchangeable attachment system, health monitoring functionality, wireless power charging, wireless authentication and transaction functionality, and other features and functionality.

## BACKGROUND

Portable electronic devices have become increasingly popular, and the features and functionality provided by portable electronic devices continue to expand to meet the needs and expectations of many consumers. However, some traditional portable electronic devices, particularly wearable electronic devices, may have relatively limited functionality or are only able to perform a specialized set of functions or tasks. For example, some traditional electronic wristwatches may be configured to perform a relatively limited set of functions, including displaying time, date, and performing basic timing functions. The embodiments described herein are directed to a wearable electronic device that provides a wide range of functionality, as compared to some traditional wearable electronic devices.

## SUMMARY

The embodiments included herein are directed to a consumer product, which may include a portable or wearable electronic device that is configured to provide an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device.

Some example embodiments are directed to wearable electronic device having a housing that includes a flat bottom portion, a top portion defining a cavity, and a curved side portion that extends from the bottom portion to the top portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A display may be at least partially disposed within the cavity and may have a viewable area. The device may also include a cover disposed above the display and including a flat middle portion larger than the viewable area of the display, a curved edge portion surrounding the flat middle portion

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and coinciding with the curved side portion along a perimeter of the cavity to form a continuous contoured surface.

In some embodiments, the continuous contoured surface is tangent with the flat bottom portion of the housing at a first end of the contour. The continuous contoured surface may also be tangent with the flat middle portion of the cover at a second end of the contour. In some embodiments, the continuous contoured surface has a constant radius.

In some embodiments, the cavity has a rectangular shape. The curved edge portion of the housing may have four sides that surround the cavity, each side is orthogonal to two adjacent sides. Each side may be connected to an adjacent side by a rounded corner. In some embodiments, the rounded corners have a curvature that corresponds to a curvature of the continuous contoured surface formed by the curved edge portion of the cover and the curved side portion of the housing.

Some embodiments include a crown module that is positioned at least partially within an aperture formed within the curved side portion of the housing. The crown module may include an outer surface configured to receive a rotary user input. The crown module may be offset with respect to a centerline of the housing between the top portion and the flat bottom portion. The offset may be toward the top portion of the housing. The crown module may include a dial having a portion that is higher than an interface between the cover and the housing.

In some example embodiments, a port is formed in the curved side portion of the housing. An acoustic module may be disposed within the housing and configured to produce an audio output through the port. The acoustic module may include an acoustic element and an acoustic cavity that acoustically couples the acoustic element to the port. The port may include an orifice that is offset with respect to the acoustic cavity to prevent the direct ingress of liquid into the acoustic module.

In some embodiments, the device includes a gasket positioned between the housing and the cover. The housing may also include a ledge formed along a perimeter of the cavity. The gasket may be positioned along the ledge that is formed along the perimeter of the cavity. The gasket, the cover, and the housing may be configured to cooperate to form a substantially water-proof seal.

In some example embodiments, the device includes a biosensor module that is disposed in an opening formed in the flat bottom portion of the housing. The biosensor module may include a chassis positioned in the opening of the housing and defining an array of windows. An array of light sources may be attached to the chassis and configured to emit light into the user through the array of windows. The biosensor module may also include an optically transparent rear cover disposed over the chassis and over the array of windows and operative to pass light emitted from the array of light sources into the user. In some embodiments, the rear cover has a convex outer contour.

Some example embodiments are directed to an electronic device having a housing comprising a bottom portion defining an opening and a band attached to the housing and configured to secure the electronic device to a user. A biosensor module may be disposed within the opening of the housing. A rear cover may be disposed over the biosensor module and may include an edge protruding outwardly from the bottom portion of the housing and an outer surface having a convex curved contour. In some embodiments, the outer surface of the rear cover defines one or more windows that provide operational access to one or more optical components of the biosensor module. The one or more

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windows may have a curvature that matches the convex curved contour of the outer surface.

In some embodiments, the biosensor module includes an array of light sources that are configured to emit light into a body of the user. The biosensor module may also include a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. In some cases, the biosensor module is removably coupled to the housing.

In some embodiments, the device also includes a processing unit configured to compute a health metric associated with the user based on the sensor signal. The device may also include a display disposed within the housing and configured to display the health metric.

Some example embodiments are directed to a wearable electronic device, having a housing including a top portion, a cavity formed within the top portion, and a curved side portion that surrounds the cavity. The device may also include a transparent cover disposed over the cavity of the housing and may include a flat middle portion at a center of the transparent cover, a curved outer portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge of the transparent cover, and a mask positioned relative to an internal surface of the transparent cover. The mask may have an outer boundary located proximate to the edge of the transparent cover and an inner boundary located within the curved outer portion of the transparent cover.

In some embodiments, the device includes a display disposed below the transparent cover. A perimeter portion of a viewable area of the display may be disposed below the mask. The device may also include an antenna having a shape that corresponds to a shape of the cavity formed within the housing. The antenna may be disposed in a groove formed in the internal surface of the transparent cover. The groove may be formed between the outer boundary and the inner boundary of the mask. In some embodiments, the cover is formed from a sapphire material. The antenna may be configured to facilitate wireless communication between the wearable electronic device and an external device.

Some example embodiments are directed to an electronic device having a housing including a first end, a second end opposite the first end, a first side extending between the first and second ends, and a second side opposite to the first side and extending between the first and second ends. The first end may define a first groove extending between the first and second sides and may be configured to receive a first lug portion of a first band. The second end may define a second groove extending between the first and second sides and may be configured to receive a second lug portion of a second band. The first and second grooves may have an inwardly curved concave shape with an undercut feature that retains the first and second lug portions. In some embodiments, the first groove extends through a solid portion of the housing to form a continuous interior shape.

In some embodiments, the device includes a display at least partially disposed within a cavity of the housing. A cover may be disposed above the display and at least a portion of the first groove is disposed below the cover. The first and second grooves may be formed at an angle with respect to a centerline of the housing. The first and second grooves may be angled upward toward a top of the housing and inward toward the center of the housing. The first and second grooves may cross the centerline of the housing.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic

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device to a user. A crown may be disposed relative to the housing and configured to receive a rotational input. An encoder may be operatively coupled to the crown and configured to produce an encoder output that corresponds to the rotational input. A speaker module may be disposed within the housing and configured to produce an audio output that corresponds to the encoder output. A haptic device may be disposed within the housing and configured to produce a haptic output that corresponds to the encoder output. In some embodiments, the haptic output is synchronized with the audio output. The crown may be further configured to translate along an axis and actuate a tactile switch.

In some embodiments, the device also includes a display element within the housing. The device may be configured to display a list of items on the display element and scroll the list of items in response to the encoder output. The device may also be configured to synchronize the audio and haptic outputs with the scrolling of the list of items. In some embodiments, the crown is further configured to translate along an axis and actuate a tactile switch. The crown may be operative to select an item of the list of items when the tactile switch is actuated.

Some example embodiments are directed to a wearable electronic device having a housing that includes a bottom portion and an aperture formed in the bottom portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A biosensor module may be disposed in the aperture of the housing. The biosensor module may include an array of light sources configured to emit light into a body of the user, and a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. The device may also include a processing unit that is configured to compute a health metric associated with the user based on the sensor signal. A display may be disposed within the housing and configured to display the health metric.

In some embodiments, the array of light sources and the photodetector are configured to function as multiple photoplethysmography (PPG) sensors. Each PPG sensor may be configured to be used to compute a separate health metric. In some embodiments, a first light source of the array of light sources includes a green LED adapted to detect blood perfusion in the body. A second light source of the array of light sources may include an infrared LED adapted to detect water content of the body. The health metric may include one or more of: a heart rate, a respiration rate, a blood oxygenation level, and a blood volume estimate.

In some embodiments, the device also includes at least one pair of electrodes disposed on an exterior surface of the housing. The at least one pair of electrodes may be configured to produce a signal when the at least one pair of electrodes is in contact with the body. In some case, the signal is used to compute an additional health metric that includes one or more of: a heart function, a body fat estimate, and a body fat estimate.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. The device may also include an array of light emitting diodes (LEDs) disposed within the housing, the array of LEDs being configured to emit light. A photodetector may be disposed within the housing and configured to receive light produced by an LED of the array of LEDs that is reflected from a body of the user and produce a first sensor signal in response to the received light. The device



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may also include at least one pair of electrodes disposed on an exterior surface of the wearable electronic device. The electrodes may be configured to produce a second sensor signal when the electrodes are in contact with a respective portion of the body. The device may also include a processing unit that is configured to compute one or more health metrics based on the first and second sensor signals. The device may also include a display disposed at least partially within the housing and configured to display the one or more health metrics.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be disposed relative to the housing and a display may be attached to a lower surface of the cover. A force sensor may be positioned between the cover and the housing and attaching the cover to the housing. The force sensor may be configured to detect the force of a touch on the cover. The force sensor may also form a barrier to prevent ingress of liquid into the wearable electronic device. In some embodiments, an antenna may be disposed relative to the cover and external from the housing. The antenna may be configured to facilitate wireless communication with an external device.

In some example embodiments, a wearable electronic device may include a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A display element may be positioned within the housing and a rechargeable battery may be disposed within the housing and operatively coupled to the display element. The device may also include a receive coil within the housing configured to inductively couple with an external transmit coil. A power conditioning circuit may be configured to recharge the rechargeable battery using power received by the receive coil. The power conditioning circuit may be configured to provide power to the display element. The device may also include a first alignment magnet positioned within the receive coil and configured to align the device with respect to a second alignment magnet positioned within the external transmit coil.

Some example embodiments are directed to a wearable electronic device that includes a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be positioned relative to the housing and a display may be disposed within the housing and below the cover. A force sensor may be disposed within the housing and configured to detect a force of a touch on the cover. A touch sensor may be disposed between the display and the cover. The touch sensor may be configured to detect a location of the touch on the cover. In some embodiments, the force sensor is disposed along a perimeter of the display. The device may also include a processing unit and memory disposed within the housing. The processing unit may be configured to interpret a touch gesture on a surface of the cover using a force output from the force sensor and a touch output from the touch sensor.

## BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements.

FIG. 1 depicts an example wearable electronic device having a device body and band.

FIG. 2 depicts an example schematic diagram of a wearable electronic device.

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FIG. 3 depicts an example functional diagram for a wearable electronic device.

FIG. 4 depicts an example wearable electronic device as part of a system of devices.

FIG. 5 depicts a system of interchangeable components for a wearable device.

FIG. 6 depicts an example wearable electronic device having a device body and band.

FIG. 7 depicts an exploded view of components of an example wearable electronic device.

FIG. 8 depicts an example housing for a wearable electronic device.

FIG. 9 depicts an example force sensor configured to use a capacitive measurement.

FIGS. 10A-B depict plan views of example force sensors.

FIG. 11 depicts an example force sensor configured to use a resistive measurement.

FIG. 12 depicts an example pixelated force sensor configured to use a resistive measurement.

FIGS. 13A-B depict example force sensor structures.

FIGS. 14A-C depict an example touch sensor based on mutual capacitance.

FIGS. 15A-B depict an example touch sensor based on self capacitance.

FIG. 16 depicts an example device having biosensors.

FIG. 17 depicts an example device having wireless communications with an external device.

FIG. 18 depicts an example electronic device and example dock of an inductive charging system.

FIG. 19 depicts a block diagram of an example inductive charging system.

FIG. 20 depicts an example acoustic module.

FIGS. 21A-B depict an example cover and antenna.

FIGS. 22A-B depict an example haptic module.

FIG. 23 depicts an example device having a crown module with an encoder.

FIGS. 24A-B depict an example device having a crown module with a tactile switch.

FIGS. 25A-C depict an example receiving feature for a band.

FIG. 26 depicts example elements of a display.

## DETAILED DESCRIPTION

Provided herein are descriptions and examples of a consumer product, which may include a portable electronic device, a wearable electronic device, or other type of device. By way of example and not by way of limitation, the consumer product may be an electronic device, a mechanical device, or an electromechanical device. Specific example devices include mobile phones, personal digital assistants, music players, timekeeping devices, health monitoring devices, tablet computers, laptop computers, glasses (electronic or otherwise), portable storage devices, and the like.

In one particular embodiment, the consumer product is a portable and, more specifically, a wearable consumer product. A wearable consumer product is one that can be worn by or otherwise secured to a user. For example, the consumer product may be a wearable electronic device including, but not limited to, a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and the like. A wearable consumer product may be worn by a user in a variety of ways. In some examples, the consumer product is a wrist-worn product and may include a band that can be wrapped around a user's wrist to secure the consumer product to the user's body. The device may include one or more other types

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of attachments including, for example, an armband, lanyard, waistband, chest strap, and the like.

Some aspects of the disclosure are directed to a wearable electronic device having improved functionality and/or versatility as compared to some traditional wearable devices. For example, some aspects of the disclosure are directed to a consumer product, such as a portable electronic device, having an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device. Some aspects of the following disclosure are directed to the integration of a variety of subsystems or modules to provide functionality that may not be possible using some traditional device platforms. In some cases, the configuration and/or functionality provided by the various subsystems may be configurable by the end user, the manufacturer, and/or a vendor of the device. Example subsystems or modules of a consumer product and their respective functions are described below with respect to FIGS. 2 and 3.

Some aspects of the disclosure are directed to a consumer product that is configured to communicate wirelessly with any of a number of other devices, such as a mobile phone, computer, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Through wireless communication with other devices, the consumer product may transmit and/or receive various notifications, messages, or other information between devices. The wireless communication may also facilitate the relay of alerts or other device outputs to notify the user of an event or action. In some aspects, the consumer product may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. An example communication system is described below with respect to FIG. 4 and with respect to other examples provided herein.

In some aspects, the consumer product may include a system of interchangeable components used to attach or secure the consumer product to the user. The system of interchangeable components may include a set of interchangeable bands or attachment devices that are configured to connect or attach to a receiving feature on the body of the product. The receiving feature may be standardized within the system of interchangeable components and allow multiple types of bands or attachment devices to be used with the same housing or body. The system of interchangeable components may also allow for an interchange between different bodies, which may include different types of electronic devices or other consumer products. Each body of the different devices or products may have a similar receiving feature that is standardized within the system of interchangeable components. An example system of interchangeable components is described below with respect to FIG. 5 and with respect to other examples provided herein.

Some aspects of the present disclosure are directed to a consumer product that includes a body that includes a case or housing used to protect as well as support the internal components of the product in their assembled position. The housing may enclose and support various components, including, for example, integrated circuits, subsystems, modules, and other internal components of the device. In

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some aspects, the housing forms a water-resistant or water-proof barrier and also provides structural rigidity necessary to protect internal components. The housing may be formed as a single piece, which may enhance the structural rigidity, water impermeability, and manufacturability of the housing. An example housing and example internal components for a consumer product are provided below with respect to FIGS. 6-8 and with respect to other examples provided herein.

In some aspects, the consumer product includes a force sensor that is configured to detect and measure the magnitude of a force or pressure on a surface of the product. In some implementations, the force sensor includes a capacitive-based sensor that is configured to estimate the force based on a deflection or movement between capacitive plates that is caused by and correlates to the amount of force caused by a touch. In some implementations, the force sensor is a resistance- or charge-based sensor that is configured to estimate the force based on the deflection of a sheet or film that is positioned relative to the touch-sensitive surface of the product. In some implementations, the output from the force sensor is combined with the output from a touch sensor, which may be self-capacitive or mutually capacitive, or a combination of the two. Example force and touch sensors are described below with respect to FIGS. 9-15B and with respect to other examples provided herein.

In some aspects, the consumer product includes one or more biosensors. The biosensors may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. Example health metrics include, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. In some embodiments, the biosensors include an electrical sensor that may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. An example consumer product having multiple biosensors is described below with respect to FIG. 16 and with respect to other examples herein.

In some aspects, the consumer product is configured to perform wireless communication with an external device. In some implementations, the wireless communication may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce. An example consumer product having wireless communications with an external device is described in more detail below with respect to FIG. 17 and with respect to other examples herein.

In some aspects, the consumer product is configured to recharge an internal battery using a wireless charging system. In some implementations, the consumer product includes one or more receiving inductive coils that are configured to cooperate with one or more transmitting inductive coils that are located in a charging dock or other external device. The wireless charging system may allow the transfer of power and/or wireless communications with the consumer product without the use of an external port or terminal connection. An example consumer product having wireless charging capabilities is described in more detail below with respect to FIGS. 18-19 and with respect to other examples herein.

In some aspects, the consumer product includes one or more acoustic modules that are configured to function as a speaker and/or a microphone for the product. The speaker and/or microphone may include features that enhance the water/liquid resistance or impermeability of the consumer



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product. The consumer product may also include a haptic module or actuator that is configured to produce a haptic output that may be perceived by the user. In some implementations, the output of an acoustic module, such as a speaker, and the haptic module may be used to provide feedback or an alert to the user. In some cases, an acoustic module and the haptic module provide feedback to the user and may be coordinated with a user input, such as user-interface selecting, user-interface scrolling, or other user input command. An example acoustic module is described below with respect to FIG. 20 and an example haptic module is described below with respect to FIGS. 22A-B.

In some aspects, the consumer product includes a dial or crown that is coupled to an encoder or other rotary sensor for detecting a rotary input. In some implementations, the output from the optical encoder is used to drive an aspect of a user interface or control other functionality of the product. Additionally, the dial or crown may include a tactile switch that can be actuated by pressing inward on the dial or crown. An example consumer product having a crown is described below with respect to FIGS. 23-24B and with respect to other examples herein.

The description that follows includes sample devices, components, modules, systems, methods, and apparatuses that embody various elements of the present disclosure. However, it should be understood that various elements of the described disclosure may be combined and/or practiced in a variety of forms in addition to those described herein. In particular, the modules and components are described in a particular combination with respect to some examples provided below. However other combinations are possible, which may be achieved by adding, removing, and/or rearranging modules to obtain a device or system having the desired characteristics.

FIG. 1 depicts a wearable consumer product 10. For example, the consumer product 10 may be a wearable electronic device. In one example, the consumer product 10 may be a wearable multifunctional electronic device including multiple functionalities such as time keeping, health monitoring, sports monitoring, medical monitoring, communications, navigation, computing operations, and/or the like. The functionalities may include but are not limited to: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating (in a wired or wireless fashion) with other electronic devices or services, which may be different types of devices having different functionalities; providing alerts to a user, which may include audio, haptic, visual and/or other sensory output, any or all of which may be synchronized with one another; visually depicting data on a display; gathering data from one or more sensors that may be used to initiate, control, or modify operations of the device; determining a location of a touch on a surface of the device and/or an amount of force exerted on the device, and using either or both as input; accepting voice input to control one or more functions; accepting tactile input to control one or more functions; capturing and transmitting images; and so on. These and other functions and features will be described in more detail herein.

The wearable consumer product 10 can take a variety of forms. In one example, the consumer product 10 may be a wrist-worn electronic device. The device may include a variety of types of form factors including, wristbands, armbands, bracelets, jewelry, and/or the like.

In the illustrated embodiment, the consumer product 10 includes a device body 11. The device body 11 may include a housing that carries, encloses and supports both externally

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and internally various components (including, for example, integrated circuit chips and other circuitry) to provide computing and functional operations for the consumer product 10. The components may be disposed on the outside of the housing, partially within the housing, through the housing, completely inside the housing, and the like. The housing may, for example, include a cavity for retaining components internally, holes or windows for providing access to internal components, and various features for attaching other components. The housing may also be configured to form a water-resistant or water-proof enclosure for the body 11. For example, the housing may be formed from as a single unitary body and the openings in the unitary body may be configured to cooperate with other components to form a water-resistant or water-proof barrier.

Examples of components that may be contained in the device body 11 include processing units, memory, display, sensors, biosensors, speakers, microphones, haptic actuators, batteries, and so on. In some cases, the device body 11 may take on a small form factor. In cases such as these, the components may be packaged and/or in order to provide the most functionality in the smallest space. The components may also be configured to take up a minimal amount of space, which may facilitate the device body 11 having a small form factor. Additionally, the integration and assembly of the various components may be configured to enhance the reliability of the consumer product 10.

The construction of the housing of the device body 11 may be widely varied. For example, housing may be formed from a variety of materials including plastic, rubber, wood, silicone, glass, ceramics, fiber composites, metal or metal alloys, (e.g., stainless steel, aluminum), precious metals (e.g., gold, silver), or other suitable materials, or a combination of these materials.

Also in the illustrated embodiment, the wearable electronic device includes a band 12 or strap or other means for attaching to a user. The band 12 may, for example, be configured to attach to the body and provide a loop for securing to the wrist of the user. The band 12 may be integral with the housing or it may be a separate part. If integral, the band 12 may be a continuation of the housing. In some cases, the integral band may be formed from the same material as the housing. If the band 12 is separate, the band may be fixed or releasably coupled to the housing. In both cases, the band 12 may be formed from similar or different materials as the housing. In most cases, the band 12 is formed from a flexible material such that it can conform to a user's body. Furthermore, the band 12 itself may be a single integral part or it may include attachment ends that provide an open and closed configuration. The attachment ends may, for example, be manifested as a clasp or other similar attachment mechanism or device. This particular configuration allows a user to open the band 12 for placement on the arm and close the band 12 in order to secure the band and body to the arm. The band 12 may be widely varied. By way of example, they may be formed from rubber, silicone, leather, metal, mesh, links and/or the like.

FIG. 2 depicts an example schematic diagram of a wearable electronic device. By way of example, device 100 of FIG. 2 may correspond to the consumer product 10 shown in FIG. 1. To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device 100, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device 100 may have

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some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

As shown in FIG. 2, the device 100 includes one or more processing units 102 that are configured to access a memory 104 having instructions stored thereon. The instructions or computer programs may be configured to perform one or more of the operations or functions described with respect to the device 100. For example, the instructions may be configured to control or coordinate the operation of a display 120, one or more input/output components 106, one or more communication channels 108, one or more sensors 110, a speaker 122, a microphone 124 and/or one or more haptic feedback devices 112.

The processing units 102 of FIG. 2 may be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processing units 102 may include one or more of: a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

The memory 104 can store electronic data that can be used by the device 100. For example, a memory can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing and control signals or data for the various modules, data structures or databases, and so on. The memory 104 can be configured as any type of memory. By way of example only, the memory can be implemented as random access memory, read-only memory, Flash memory, removable memory, or other types of storage elements, or combinations of such devices.

In the schematic diagram of FIG. 2, the one or more input components 106 are represented as a single item within the schematic diagram. However, input components 106 may represent a number of different input components, including buttons, switches, and dials for accepting user input, and so on. More specifically, the input components 106 may correspond to the buttons, dials, crowns or other devices for receiving input. Generally, the input components 106 are configured to translate a user-provided input into a signal or instructions that may be accessed using instructions executed on the processing units 102. In the present example, the input components 106 may include the hardware configured to receive the user input (e.g., button, switch, crown, and encoder) which is operatively coupled to circuitry and firmware used to generate signals or data that are able to be accessed using processor instructions. Each input component 106 may include specialized circuitry for generating signals or data and, additionally or alternatively, circuitry and firmware for generating signals or data may be shared between multiple input components 106. In some cases, the input components 106 produce user-provided feedback for application-specific input that corresponds to a prompt or user interface object presented on display 120. For example, the crown (item 642 of FIG. 6) may be used to receive rotational input from the user, which may be translated into an instruction to scroll a list or object presented on the display 120. The input components 106 may also produce user input for system-level operations. For example the input components 106 may be configured to interact directly with hardware or firmware being executed on the device 100

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for system-level operations, including, without limitation, power on, power off, sleep, awake, and do-not-disturb operations.

As shown in FIG. 2, the device 100 may also include one or more acoustic elements, including a speaker 122 and a microphone 124. The speaker 122 may include drive electronics or circuitry and may be configured to produce an audible sound or acoustic signal in response to a command or input. Similarly, the microphone 124 may also include drive electronics or circuitry and is configured to receive an audible sound or acoustic signal in response to a command or input. The speaker 122 and the microphone 124 may be acoustically coupled to respective ports or openings in the housing that allow acoustic energy to pass, but may prevent the ingress of liquid and other debris. As shown in FIG. 2, the speaker 122 and microphone 124 are also operatively coupled to the processing units 102, which may control the operation of the speaker 122 and microphone 124. In some cases, the processing units 102 are configured to operate the speaker 122 to produce an acoustic output that corresponds to an application or system-level operation being performed on the device 100. In some cases, the speaker 122 is operatively coupled to other modules, including, for example, input components 106, such as a crown or button. In some implementations, the device 100 is configured to produce an audible output that corresponds to the operation of the crown or buttons using the speaker 122. The microphone 124 may be configured to produce an output or signal in response to an acoustic stimulus. For example, the microphone 124 may be operatively coupled to the memory 104 and may be configured to record audio input, including human speech, music, or other sounds. In some cases, the microphone 124 may be configured to receive voice signals, which may be interpreted as voice commands by the processing units 102.

The one or more communication channels 108 may include one or more wireless interface(s) that are adapted to provide communication between the processing unit(s) 102 and an external device. In general, the one or more communication channels 108 may be configured to transmit and receive data and/or signals that may be interpreted by instructions executed on the processing units 102. In some cases, the external device is part of an external communication network that is configured to exchange data with wireless devices. Generally, the wireless interface may include, without limitation, radio frequency, optical, acoustic, and/or magnetic signals and may be configured to operate over a wireless interface or protocol. Example wireless interfaces include radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces.

In some implementations, the one or more communications channels 108 may include a dedicated wireless communication channel between the device 100 and another user device, such as a mobile phone, tablet, computer, or the like. In some cases, output, including audio sounds or visual display elements, are transmitted directly to the other user device for output to the user. For example, an audible alert or visual warning may be transmitted to a user's mobile phone for output on that device. Similarly, the one or more communications channels 108 may be configured to receive user input provided on another user device. In one example, the user may control one or more operations on the device 100 using a user interface on an external mobile phone, tablet, computer, or the like.



Additionally, as described in more detail below with respect to FIG. 17, the communications channels 108 may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce.

As shown in FIG. 2, the device 100 also includes one or more sensors 110 represented as a single item within the schematic diagram. However, the sensors 110 may represent a number of different sensors, including devices and components that are configured to detect environmental conditions and/or other aspects of the operating environment. Example sensors 110 include an ambient light sensor (ALS), proximity sensor, temperature sensor, barometric pressure sensor, moisture sensor, and the like. Thus, the sensors 110 may also be used to compute an ambient temperature, air pressure, and/or water ingress into the device. In some embodiments, the sensors 110 may include one or more motion sensors for detecting movement and acceleration of the device 100. The one or more motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device.

The device 100 also includes one or more biosensors 118 and may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. As described in more detail below with respect to FIG. 16, one or more of the biosensors 118 may include a light source and a photodetector to form a photoplethysmography (PPG) sensor. The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics including, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. One or more of the biosensors 118 may also be configured to perform an electrical measurement using one or more electrodes. The electrical sensor(s) may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, one or more of the biosensors 118 may be configured to measure body temperature, exposure to UV radiation, and other health-related information.

The device 100 may also include one or more haptic devices 112. The haptic device 112 may include one or more of a variety of haptic technologies such as, but not necessarily limited to, rotational haptic devices, linear actuators, piezoelectric devices, vibration elements, and so on. In general, the haptic device 112 may be configured to provide punctuated and distinct feedback to a user of the device. More particularly, the haptic device 112 may be adapted to produce a knock or tap sensation and/or a vibration sensation. As shown in FIG. 2, the haptic device 112 may be operatively coupled to the processing unit 102 and memory 104. In some embodiments, the haptic device 112 may be directly controlled by the processing unit 102. In some embodiments, the haptic device 112 may be controlled, at least in part, by the operation of an input component 106, including, for example, a button, dial, crown, or the like. The operation of the haptic device 112 may also be paired or linked to the operation of one or more other output devices, including, for example, the display 120 or the speaker 122.

As shown in FIG. 2, the device 100 may include a battery 114 that is used to store and provide power to the other components of the device 100. The battery 114 may be a rechargeable power supply that is configured to provide power to the device 100 while it is being worn by the user. The device 100 may also be configured to recharge the

battery 114 using a wireless charging system. Accordingly, in some cases, the device may include a wireless power module 116 that may be configured to receive power from an external device or dock. The wireless power module 116 may be configured to deliver power to components of the device, including the battery 114. The wireless power module 116 and an external charging station or dock may also be configured to transmit data between the device and a base or host device. In some cases, the wireless power module 116 may interface with the wireless charging station or dock to provide an authentication routine that is able to identify specific hardware, firmware, or software on the device in order to facilitate device maintenance or product updates. A more detailed description of an example wireless charging station is provided below with respect to FIGS. 18-19.

The device 100 may include a variety of other components, including for example, a camera or camera modules. The camera may be configured to capture an image of a scene or subject located within a field of view of the camera. The image may be stored in a digital file in accordance with any one of a number of digital formats. In some embodiments, the device 100 includes a camera, which includes an image sensor formed from a charge-coupled device (CCD) and/or a complementary metal-oxide-semiconductor (CMOS) device. The camera may also include one or more optical components disposed relative to the image sensor, including, for example, a lens, an filter, a shutter, and so on.

FIG. 3 depicts functional elements of the device 100, in accordance with some embodiments. In particular, FIG. 3 depicts the inputs that may be received and outputs that may be produced on an example device 100. By way of example, the device 100 may correspond to the devices shown in FIGS. 1 and 2. As shown in FIG. 3, the device 100 may include a force input 302 that may be produced using a force sensor that is configured to detect and measure the magnitude of a force of a touch on a surface of the device. The force input 302 may include a non-binary output that is generated in response to a touch. For example, the force input 302 may include a range of values or analog value that corresponds to the amount of force exerted on a surface of the device. Additionally or alternatively, the force input 302 may include binary (e.g., on, off) output in response to the force of a touch. The force input 302 may be used to control various aspects of the device. For example, the force input 302 may be used to control an aspect, such as a cursor or item selection on a user interface presented on the display of the device. The force input 302 may also be used to control the audio output 308, haptic output 312, and other functionality of the device. The force input 302 may also be used to distinguish between different types of input from the user. For example, a light touch from the user may be interpreted as a scroll command and used to index or scroll through a list of items on the display. A harder touch from the user may be interpreted as a selection or confirmation of an item on the display. In some embodiments, the force input 302 is used to distinguish an intentional touch from the user from an incidental or accidental touch that may be ignored.

As shown in FIG. 3, the device 100 may also include a touch input 306 that may be produced using a touch sensor that is configured to detect and measure the location of a touch on a surface of the device. In some implementations, the touch sensor is a capacitive-based touch sensor that is disposed relative to the display or display stack of the device. The touch sensor may be a separate non-integrated sensor relative to the force sensor. In alternative embodiments, the touch sensor may also be physically and/or logically integrated with the force sensor to produce a



combined output. The touch input 306 may be used to control various aspects of the device. For example, the touch input 306 may be used to control an aspect of the user interface presented on the display of the device. The touch input 306 may also be used to control the audio output 308, haptic output 312, and other functionality of the device.

In some cases, the logical integration of the force input 302 and the touch input 306 enhances the versatility or adaptability of device 100 by enabling a more sophisticated user interface than is currently available on some traditional wearable devices. In particular, the force input 302 and the touch input 306 may be combined to interpret a wider range of gestures and input commands than may be possible using, for example, only a touch input. For example, the force input 302 may provide a magnitude of a force of a touch, which may be used to distinguish between two touch input commands that have a similar location or gesture path. An improved touch interface using both force input 302 and touch input 306 may be particularly advantageous when interpreting touch commands on a relatively small area surface, such as a display screen or cover glass of a wearable electronic device.

As shown in FIG. 3, the device 100 may also include a button/dial input 310 that may be produced using an input device that is configured to receive input from the user. As described previously, the device 100 may include one or more buttons disposed on or near an external surface of the housing and are configured to receive input from a user. The device may also include a dial or crown that is configured to accept rotational input from the user. As described in more detail below with respect to FIGS. 24A-B, the dial or crown may also include a push feature that is adapted to accept input from the user.

The device 100 may also accept audio input 314 using a microphone or other acoustic sensing device. The audio input 314 may be adapted to accept input from the user, including voice commands and other audio signal input. The audio input 314 may also be adapted to detect and measure ambient audio conditions that may be used to adjust the volume of the audio output 308 or operation of the haptic output 312. The audio input 314 may also be used to record an audio stream or voice message in accordance with an audio recording application or software program.

As shown in FIG. 3, the device 100 may include a display output 304 in accordance with some embodiments. The display output 304 includes visual or graphical output that may be produced using the display element of the device. In some embodiments, the display output 304 includes a graphical user interface produced using an operating system or software application executed on one or more processing units of the device. In one example, the display output 304 includes a graphical depiction that resembles a watch face or other timekeeping device. In other examples, the display output 304 includes a graphical interface for an e-mail, text messaging, or other communication-oriented program. The display output 304 may also present visual information that corresponds to one of the other functional aspects of the device 100. For example, the display output 304 may include information that corresponds to the biosensor input 320, sensor input 318, force input 302, touch input 306, and others.

As shown in FIG. 3 the device 100 may include an audio output 308 that may be produced with a speaker or acoustic module. The audio output 308 may include sounds or audio signals that are associated with the operation of the device. For example, the audio output 308 may correspond to the operation of an input device to provide audio feedback to the

user. For example the audio output 308 may correspond to an input received in the form of a force input 302, touch input 306, and/or button/dial input 310. In some cases, the audio output 308 may also include a portion of an auditory alert that may be produced alone or combined with a haptic output 312 and/or display output 304 of the device 100.

The device 100 may also include a sensor input 318 produced using one or more sensors that may be configured to monitor and detect various environmental conditions. For example, the sensor input 318 may include signals or data produced using an ambient light sensor, proximity sensor, temperature sensor, barometric pressure sensor, or other sensor for monitoring environmental conditions surrounding or near the device. In general, the sensor input 318 may be used to adapt the functionality of the device 100 to conform to the one or more environmental conditions. For example, the brightness of the display output 304, the volume of the audio output 308, and/or the operation of the input to the device 100 may be based on the sensor input 318.

In some embodiments, the sensor input 318 includes input produced by one or more motion sensors. The motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device. A sensor input 318 produced using one or more motion sensors may be used to monitor and detect changes in motion of the device 100. Changes in linear and angular motion may be used to determine or estimate an orientation of the device relative to a known location or fixed datum. The sensor input 318 produced from the one or more motion sensors may also be used to track the movement of the user. The movement of the user may be used to facilitate navigation or map-guided functionality of the device. Additionally, input related to the gross movement of the user can be used as a pedometer or activity meter, which may be stored and tracked over time to determine health metrics or other health-related information. Additionally, in some embodiments, sensor input 318 from the one or more motion sensors may be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty).

The device 100 may also include a biosensor input 320 produced using one or more biosensors or biosensor modules that are configured to monitor physiological and/or health conditions of a user. As discussed above with respect to FIG. 2, the device may include one or more optical sensors for measuring heart rate, blood pressure, oxygen saturation, or a combination thereof. The device may also include one or more sensors having electrical contacts that are disposed to contact the user's body. The sensors may be configured to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, sensors may be configured to measure body temperature, exposure to UV radiation, and other health related information. The biosensor input 320 may be combined with other aspects of the device to provide health-monitoring functionality. For example, the biosensor input 320 may be used to compute data that is presented using the display output 304. The operation of the biosensor input 320 may also be controlled using the force input 302, touch input 306, or other user input 310 to provide an interactive health monitoring function or application.

As shown in FIG. 3, the device may include a haptic output 312 that may be produced using one or more haptic devices that are configured to provide haptic feedback to the user. In particular, the haptic output 312 may be produced

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using one or more electromechanical subassemblies that are configured to induce motion or vibration in the device, which may be perceived or sensed by the user. In some cases, the haptic actuator or device is tuned to operate based on a resonance or near resonance with respect to the device, which may enhance haptic output. In some cases, the haptic actuator or device is configured to operate based on a resonance or near resonance with respect to some components of the device, such as the band or clasp of the device.

In some embodiments, the haptic output 312 may correspond to the operation of one or more other modules or subsystems. For example, the haptic output 312 may include a vibration or haptic feedback that corresponds to an audio alert or visual alert or signal produced by the acoustic module or display, respectively. Additionally or alternatively, the haptic output 312 may be operated in conjunction with an input from the user. The haptic output 312 may include haptic or force feedback that confirms that the user input was or is being received. By way of example, a haptic output 312 may include a click or vibration when the crown of the device is turned or a button is depressed. The haptic output 312 may also be coordinated with other functionality of the device including, for example, message transmission operations, power management operations, force sensor operations, biosensor operations, to provide a notification, to provide an alert, and others.

As shown in FIG. 3, the device 100 may also include communications input/output (I/O) 316, which may facilitate communication with an external device or system. The communications I/O 316 may be produced using one or more wireless interfaces, including radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. In some cases, the communications I/O 316 may include signals and data received from an external device that has been paired or is otherwise in electronic communication with the device 100. The external data included in the communications I/O 316 may include, for example, message data associated with an electronic communication, notification data associated with an event, and/or data related to audio or visual content. The communications I/O 316 may also include an authorization or identification of external devices in communication with the device 100 or users associated with one or more external devices. Similarly, the communications I/O 316 may be used to output various forms of data or signals to one or more devices or systems that are external to the device 100. For example, the communications I/O 316 may include data or computations that are produced using the biosensor input 320 and/or the sensor input 318.

FIG. 4 depicts an example wearable electronic device 100 as part of a system of devices. By way of example, the wearable electronic device 100 of FIG. 4 may correspond to the devices shown in any of the previous figures. Generally, the wearable electronic device 100 may communicate wirelessly with any of a number of other devices, such as mobile phone 420, computer 430, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Additionally, the wearable electronic device 100 may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, dis-

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play screens, and so on. Communication may be through a wired or wireless connection, including any technology mentioned herein.

In some embodiments the wearable electronic device 100 may accept a variety of bands, straps, or other retention mechanisms (collectively, "bands"). These bands may be removably connected to the electronic device by a feature formed into the band or band assembly that is accepted in a recess or other aperture within the device and locks thereto.

An example band interface is described in more detail below with respect to FIGS. 25A-C.

In general, a user may change combinations of bands and electronic devices, thereby permitting mixing and matching of the two categories. It should be appreciated that devices having other forms and/or functions may include similar recesses and may releasably mate with a lug and/or band incorporating a lug. In this fashion, a system of bands and devices may be envisioned, each of which is compatible with another. A single band may be used to connect to devices, as one further example; in such embodiments the band may include electrical interconnections that permit the two devices to transmit signals to one another and thereby interact with one another.

Insofar as the electronic device 100 may connect either physically or through a data communication link with other computing devices, the combination of devices and bands may be thought of as an ecosystem having multiple parts that interact with one another, may intelligently communicate with one another, may share functionality and/or may substitute for one another in terms of operations, output, input and the like. Examples of devices existing in such an ecosystem follow, but are illustrative rather than limiting.

As one example, a number of electronic devices 100, 420, 430 may each have identical or similar attachment structures that permit them to share a band or connector. A user may thus change the interconnected band and device(s) with respect to one another, permitting a number of different physical connections between different ecosystem components. In some embodiments, a band that serves to retain an electronic device only may be swapped for bands having additional functionalities, such as transmitting data between devices connected to the band, adding functionality to a connected device that the device lacks, providing additional power to a connected device, and so on. Further, different bands may look different, so that the appearance of the electronic device(s) in combination with a band(s) may change by changing the band(s) and/or device(s) with respect to one another.

As another example, electronic devices 100, 420, 430 may communicate with one another as part of the overall ecosystem. Data may be passed from one device 420 to another 100. This may be useful if the user 410 is wearing one electronic device 100 but is not near another device 430 that wishes to notify the user or interact with the user in some fashion. Continuing the example, the computer 430 may transmit a reminder or message to the wearable device 100 to gain the user's attention. As another example, the computer 430 (or any other electronic device in the ecosystem) may transmit a state of an application or even the device itself to the wearable device 100. Thus, for example, if an application operating on the computer needs the user's attention, it may be gained through an alert issued by the wearable device.

Data communication between devices in an ecosystem may also permit the devices to share functionality. As one non-limiting example, electronic devices may share sensor data with one another to permit one device access to data it



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normally would not have, from a sensor it does not physically incorporate. Thus, any given device **100**, **420**, **430** may draw on the abilities of other devices in the ecosystem to provide an enhanced and relatively seamless experience for a user **410**.

FIG. 5 depicts a system **500** of interchangeable components for a wearable device. By way of example, one or more of the devices of FIG. 5 may correspond to the devices shown in any of the previous figures. FIG. 5 depicts a system **500** including a variety of interchangeable components, including multiple device bodies **515**, **525**, **535** that are configured to connect via a standard interface to any one of a number of different bands **551a-b**, **552a-b**, **553a-b**, **554a-b**, and **555a-b**. In addition, each of the three devices may be configured to connect via a standard interface to another type of non-band component, such as a lug **556a-b**, non-band component, or other device.

As shown in FIG. 5, the system **500** may include a body or device that is adapted to attach to one or more bands, straps, or other similar component that may be used to attach the device to the body of a user. In some embodiments, the device may be interchangeable or interchanged to provide a different set of functions or features. In some embodiments, the bands or attachment components may be interchangeable or interchanged to provide desired functionality or features.

In the example depicted in FIG. 5, each of the devices includes at least one receiving feature **504** that is configured to interconnect with a corresponding feature **502** that is attached to or integrally formed with the end of each of the bands or other mating parts. In some embodiments, receiving feature **504** includes a channel or groove that is formed in one end of the device body. The mating feature **502** of a respective band or component may be configured to slidably engage with the receiving feature **504** of a respective device body to attach the band or component. An example receiving feature is described in more detail below with respect to FIGS. 25A-C. In some embodiments, the receiving feature **504** and the mating feature **502** are standardized in the system **500** and, thus, any of the bands (**551a-b**, **552a-b**, **553a-b**, **554a-b**, and **555a-b**) can be interchangeably used with any of the device bodies **515**, **525**, **535**.

With respect to FIG. 5, each of the bands may be formed from a different material or using a different construction. In the present example, bands **551a-b** may be formed from a textile material that may be constructed from a pattern of thread or fiber material. The textile material may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **552a-b** may be formed from a woven material and may be constructed from an array of warp fibers or threads interwoven with one or more weft fibers or threads. Similarly, the warp and weft fibers may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **553a-b** may be formed from leather material **553a-b**. In one example, the bands **553a-b** are formed from a sheet or strip of cowhide; however, the bands **553a-b** may also be formed from one of any number of types of animal hide. The leather material **553a-b** may also include a synthetic leather material, such as vinyl or plastic. The bands **554a-b** may be formed from a metallic mesh or link construction. For example the bands **554a-b** may be formed from a Milanese mesh or other similar type of construction. The bands **555a-b** may be formed from a silicone or other elastomer material.

In some cases, the band is a composite construction including various materials, which may be selected based on the end use or application. In some embodiments, a first

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band strap, or a first portion of the first band strap, may be made up of a first material and a second band strap, or a second portion of the second band strap, may be made from a second, different material. The band may also be made up of a plurality of links and, as such, the band may be resizable by, for example, adding or removing links. Example bands and band constructions are provided below in Section 12.

In the system **500**, an interchangeable band may allow for individual customization of the device or to better adapt the device for a range of uses or applications. In some instances, the type of band that is selected and installed can facilitate a particular user activity. For example, band **551a-b** may be formed from a textile material and include a durable clasp that may be particularly well suited for exercise or outdoor activities. Alternatively, as discussed above the band **554a-b** may be formed from a metallic material and include a thin or low-profile clasp that may be well suited for more formal or fashion-focused activities.

In some embodiments, the band may be coupled to a separate component having the mating feature **502**. The band may be coupled using pins, holes, adhesives, screws, and so on. In yet other embodiments, the band may be co-molded or overmolded with at least a portion of the component having the mating feature **502**. In some embodiments, the band is coupled to the component via a pin that allows the straps to rotate with respect to the component. The pin may be formed integrally with or disposed in a loop formed in the end of the band.

In the example system **500**, each of the bands is shown as having a generic band clasp. However, the type of band clasp that is used may vary between embodiments. On example band clasp may include a first band strap having a buckle or tang assembly which is configured to interface with a second band strap having a series of apertures or holes formed with the strap. Additionally or alternatively, the bands may include a magnetic clasp having one or more magnetic elements on a first band strap that is configured to mate to one or more magnetic or ferromagnetic elements on a second band strap.

As shown in FIG. 5, the system may include multiple device bodies **515**, **525**, **535** that may vary in size, shape, and composition. The device body **515**, **525**, **535** may include one or more of the embodiments described herein and may include, but is not limited to a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and/or the like. In particular, the device body may correspond to the device body described with respect to device body **610** of device **100** (shown in FIG. 6).

#### 1. Example Wearable Electronic Device

FIG. 6 depicts an example wearable electronic device, which may include various aspects of the device(s) described above. In some embodiments, multiple modules or subsystems are physically and operationally integrated together to provide particular functionality or device features. In particular, the interaction between the subsystems, or the subsystems themselves, may be configurable by the user, manufacturer, or vendor to adapt the device to produce certain functionality. Some example combinations and interactions between the various modules and subsystems are expressly provided in the present description. However, the combinations and interactions provided herein are merely illustrative in nature and are not intended to be limiting on the scope of the disclosure.

FIG. 6 depicts an example configuration of a wearable electronic device **100**. In particular, FIG. 6 depicts an electronic wearable device **100** including a device body **610**

that may be configured to be attached to the wrist of a user using a band assembly 620. This configuration may also be referred to herein as a wearable device, a device, an electronic wristwatch, or an electronic watch. While these terms may be used with respect to certain embodiments, the functionality provided by the example electronic wearable device 100 may be substantially greater than or vary with respect to many traditional electronic watches or timekeeping devices.

In the present example, the exterior surface of the device body 610 is defined, in part, by the exterior surface of the housing 601 and the exterior surface of the cover 609. In the example depicted in FIG. 6, the device body 610 is substantially rectangular with round or curved side portions. The outer surfaces of the cover 609 and the housing 601 coincide at a joint interface and cooperate to form a continuous contoured surface. The continuous contoured surface may have a constant radius and may be tangent to a flat middle portion of the cover 609 and/or a flat bottom portion of the housing 601. In some embodiments, the cover 609 has substantially the same shape as a flat bottom portion and at least a portion of the curved side portions of the housing 601. A more complete description of the geometry of the cover 609 and the housing 601 is provided below with respect to FIGS. 7 and 8.

In the example of FIG. 6, the device 100 includes a display (item 120 of FIG. 2) that is disposed at least partially within an opening or cavity defined within a top portion of the housing 601 of the device body 610. The display may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user and may be operated in accordance with one or more display modes or the software applications being executed on the device 100. By way of example, the display may be configured to present the current time and date similar to a traditional watch or timepiece. The display may also present a variety of other visual information that may correspond to or be produced using one of the other modules in the device 100. For example, the display may be configured to display one of a variety of notification messages, which may be generated based on data received from the one or more sensors, the wireless communication system, or other subsystem of the device 100. The display may also be configured to present visual information or data that is based on the output of one or more sensor outputs. The display may also provide status or information related to a wireless charging process or battery power. The display may also present visual output or information related to media being produced using a speaker or acoustic module of the device 100. Accordingly, a variety of other types of visual output or information may be presented using the display.

In the current example, the display includes or is integrated with a cover 609 that helps to protect the display from physical impact or scratches. In the field of wearable devices, the cover 609 may also be referred to generically as a crystal or cover glass, regardless of the material that is used to form the cover 609. In some cases, the cover 609 is formed from a sheet or block of sapphire material. Sapphire may provide superior optical and surface hardness properties as compared to other materials. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. In alternative embodiments, the cover 609 is formed from a glass, polycarbonate, or other optically transparent material. The cover 609 may also be coated with one or more optical or mechanical enhancing materials or surface treat-

ments. For example, interior and/or exterior surfaces of the cover 609 may be coated with an anti-reflective (AR), oleophobic or other coating to enhance the visible or functional properties of the display. Additionally, in some cases, the cover 609 may be configured to cooperate with an antenna used to facilitate wireless communication with an external device. FIGS. 21A-B, described in more detail below, provide one example embodiment of a cover configured to cooperate with an antenna.

In the example depicted in FIG. 6, the cover 609 is formed from a transparent material and, when assembled has an external surface and an internal surface. The cover 609 is disposed above the display and encloses a cavity or opening formed in the top portion of the housing 601. In some embodiments, the external surface of the cover 609 cooperates with the external surface of the housing to form a substantially continuous external peripheral surface of the electronic device. As shown in FIG. 6, the external surface of the cover 609 has a flat middle portion at the center of the cover, which extends outwardly. The cover 609 also includes a curved edge portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge at the side of the cover 609. In some embodiments, the cover 609 also includes an opaque mask disposed relative to the internal surface of the transparent cover. The opaque mask may correspond to or otherwise define the viewable area of the display 120. The mask may have an outer boundary that is located proximate the edge of the side of the cover 609 and has an inner boundary located within the curved edge portion of the cover 609.

As shown in FIG. 6, the cover 609 is disposed relative to a top portion of the housing 601. The housing 601 includes a top portion defining an opening, which is surrounded by a curved side portion. In the present example, the curved edge portion of the cover 609 coincides with the curved side portion of the housing 601 to form a continuous external surface of the electronic device 100. In some instances, the cover 609 may have a contour that follows or otherwise corresponds to a similar contour of the housing 601 to form a substantially continuous surface at the interface between the two components. As shown in FIG. 6, the cover 609 protrudes above the housing 601.

In some instances, the cover 609 is disposed relative to a touch sensor (item 702 of FIG. 7). In some embodiments, the touch sensor may be integrated with the display or other element of the device 100. The touch sensor may be formed from one or more capacitive sensor electrodes or nodes that are configured to detect the presence and/or location of an object or the user's finger that is touching or nearly touching the surface of the display. In some cases, the touch sensor includes an array of sensing nodes formed in accordance with a mutual capacitance sensing scheme.

In one example, the touch sensor may include an array of mutual capacitance touch nodes that can be formed by a two-layer electrode structure separated by a dielectric material. One layer of electrodes may comprise a plurality of drive lines and another layer of electrodes may comprise a plurality of sense lines, and where the drive lines and the sense lines cross, mutual capacitive sense nodes are formed (also referred to as coupling capacitance). In some implementations, the drive lines and sense lines may cross over each other in different planes separated from one another by a dielectric. Alternatively, in other embodiments the drive lines and sense lines can be formed substantially on a single layer. An example touch sensor and touch-sensing node are described in more detail below with respect to FIGS. 14A-C and 15A-B.



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Alternatively or additionally, the touch sensor may include one or more self-capacitive nodes or electrodes that are configured to detect a discharge of electrical current or charge when an object, such as a user's finger, contacts or nearly contacts a surface of the housing 601 or other surface of the device 100. Other types of electronically sensing nodes, including resistive, inductive, or the like, may also be integrated into a surface of the device 100.

In some embodiments, the device 100 may also include a force sensor (item 705 of FIG. 7). The force sensor may be disposed relative to the display 120 or integrated with other elements of the device 100. In some cases, the force sensor includes one or more force sensing structures or force-sensing nodes for detecting and measuring the magnitude of a force or pressure due to a touch on a surface of the device 100. The force sensor may be formed from or implement one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a force or pressure due to a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on the deflection. Example force sensor and force-sensing modules are described in more detail below with respect to FIGS. 9-12.

As shown in FIG. 6, the device 100 also includes device body 610 including a housing 601 that upon which may be mounted or integrated with various components of the device 100. The housing 601 serves to surround at a peripheral region as well as support the internal components of the product in their assembled position. In some embodiments, the housing 601 may enclose and support internally various components (including for example integrated circuit chips and other circuitry) to provide computing and functional operations for the device 100. The housing 601 may also help define the shape or form of the device. That is, the contour of the housing 601 may embody the outward physical appearance of the device. As such, it may include various ornamental and mechanical features that improve the aesthetical appearance and tactile feel of the device. For example, the housing 601 may include a contoured surface that includes rectilinear contours, curvilinear contours, or combinations thereof. The housing 601 may also include various surface features, including textures, patterns, decorative elements, and so on.

In the present example, the housing 601 is formed from a single piece, which may also be referred to as single-body, unitary, or uni-body design or construction. By utilizing a single-body construction, the structural integrity of the device may be improved as compared to a multi-piece construction. For example, a single body may be more easily sealed from contaminants as compared to a multi-piece enclosure. Additionally, a single-body enclosure may be more rigid due, in part, to the absence of joints or seams. The rigidity of the housing 601 may be further enhanced by increasing the material thickness in areas where mechanical stress may be greatest, while also maintaining or thinning other areas where mechanical stress may be lower or reduced. Variations in the thickness of the housing 601 may be possible by machining or casting the housing 601 as a single piece. Additionally, a single-body housing 601 may include one or more features for mounting or integrating the internal components of the device 100, which may facilitate manufacturing and/or assembly of the device 100.

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An example housing 601 is described in more detail below with respect to FIG. 8. The housing 601 may be formed from a variety of materials, including, without limitation plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, magnesium), other suitable materials, or a combination of these materials. Further, the housing 601 may include a surface treatment or coating, which may be formed from a variety of materials, including, without limitation aluminum, steel, gold, silver and other metals, metal alloys, ceramics, wood, plastics, glasses, and the like.

As discussed above, the display, the touch sensor, and force sensor may be disposed within the housing 601. In this example, one or more buttons 644 and a crown 642 used to receive user input may also be disposed within or relative to the housing 601. Other types of user input, including for example, one or more dials, slides, or similar user input devices or mechanisms may also be disposed within or relative to the housing 601. As described in more detail with respect to FIGS. 7 and 8, the housing 601 may include various features for attaching and mounting the subassemblies and modules of the device 100. In particular, the housing 601 may have one or more openings for receiving the cover 609, the display, the force sensor, or other components. The housing 601 may also include one or more holes or openings for receiving the button 644 and crown 642 that are located around the perimeter of the device 100. In some embodiments, the housing 601 also includes internal features, such as bosses and threaded portions, that can be used to attach modules or components within the housing 601.

The device 100 may also include an ambient light sensor (ALS) that is configured to detect and measure changes in ambient lighting conditions. The ALS may include a photodiode and one or more optical elements or lenses for collecting light. An ALS may be located on an external facing surface that is less likely to be blocked when the device is worn or in use. The ALS may be used to adjust settings, including screen brightness and other visual output depending on the overall lighting conditions.

The housing 601 may also include one or more motion-sensing elements or devices for detecting motion of the device 100. For example, the device 100 may include one or more accelerometers that are configured to sense acceleration or changes in motion. Additionally or alternatively, the device 100 may include one or more gyroscopic sensors that are configured to detect changes in direction. In some cases, the one or more gyroscopic sensors may include a spinning mass that can be used to detect changes in angular velocity. Multiple motion-sensing elements may be used to detect motion along multiple directions or axes. The motion sensors may also be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty). The one or more motion-sensing elements may be used to determine an orientation of the device relative to a known or fixed datum. For example, the device may include a compass and/or global positioning system (GPS) that can be used to identify an absolute position. The one or more motion sensing elements may then measure deviation or movement with respect to the absolute position to track movement of the device or the user wearing the device. In some implementations, the one or more motion-sensing elements are used to detect gross movement of the device or user. The gross movement may be used as

a pedometer or activity meter, which may be tracked over time and used to calculate a health metric or other health-related information.

Described in more detail with respect to FIG. 8, the housing 601 may also include one or more openings or orifices coupled to an acoustic module or speaker 122, which may include a speaker and/or a microphone subassembly. Although the housing 601 may include one or more openings or orifices, the housing 601 may still be substantially waterproof/water resistant and may be substantially impermeable to liquids. For example, the opening or orifice in the housing or enclosure may include a membrane or mesh that is substantially impermeable to liquid ingress. Additionally or alternatively, the geometry of the opening or orifice and other internal features of the housing 601 may be configured to reduce or impede the ingress of liquid or moisture into the device 100. In one example, the opening is formed from one or more orifices that are offset with respect to an internal acoustic chamber or cavity, which may prevent a direct path from the outside of the housing 601 into the acoustic module.

As shown in FIG. 6, the device 100 includes a device body 610 that may be attached to a user's wrist using a band 620. In the present example, the band 620 include a first band strap 621 attached to a first receiving feature 623 and a second band strap 622 attached to a second receiving feature 624. In some embodiments, the first and second band straps 621, 622 include a lug feature that is configured to attach to the first and second receiving features 623, 624, respectively. As shown in FIG. 6, the free ends of the band straps 621, 622 are connected with a clasp 625.

The band straps 621, 622 are formed from a flexible or compliant material that may be specially configured for a particular application. The band straps 621, 622 may be formed from a variety of materials, including, for example, leather, woven textiles, or metallic mesh materials. The material and construction of the band straps 621, 622 may depend on the application. For example, the band straps 621, 622 may be formed from a woven textile material configured for exposure to impact and moisture typically associated with outdoor activities. In another example, the band straps 621, 622 may be formed from a metallic mesh material that may be configured to have a fine finish and construction that may be more appropriate for professional or social activities.

Similarly, the clasp 625 of the band 620 may be configured for a particular application or to work with a particular style of band. For example, if the band straps 621, 622 are formed from a metallic mesh material, the clasp 625 may include a magnetic clasp mechanism. In the present example, the device 100 is configured to be attached to the wrist of a user. However, in alternative embodiments, the device may be configured to be attached to the arm, leg or other body part of the user.

The housing 601 includes one or more features for attaching the band straps 621, 622. In the present example, the housing 601 includes a first receiving feature 623 and a second receiving feature 624 for attaching the first band strap 621 and the second band strap 622, respectively. In this example, the band straps 621, 622 include a lug portion that is adapted to mechanically engage with the receiving features 623, 624. A more detailed description of the receiving features and lugs is provided below with respect to FIGS. 25A-C. As shown in FIG. 6, the first 623 and second receiving features 624 may be integrally formed into the housing 601. In alternative embodiments, the receiving features may be formed from separate parts and may be attached to the housing 601 during manufacturing. In some

embodiments, the receiving features 623, 624 may be configured to release the band straps 621, 622 from the device body 610 (e.g., the housing 601). For example, one or both of the receiving features 623, 624 may include a button or slide, which may be actuated by the user to release a corresponding band strap 621 and 622. One advantage of a releasable lug is that the user can swap between a variety of bands that may be specially configured for a particular use scenario. For example, some bands may be specially configured for sport or athletic activities and other bands may be configured for more formal or professional activities.

The device 100 may also include a rear cover 608 located on the rear-facing surface of the housing 601 of the device body 610. The rear cover 608 may improve the strength and/or scratch resistance of the surface of the device 100. For example, in some embodiments, the rear cover 608 may be formed from a sapphire sheet, zirconia, or alumina material having superior scratch resistance and surface finish qualities. In some cases, the sapphire material has a hardness greater than 6 on the Mohs scale. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. Due to the superior strength of the sapphire material, a cover glass formed from a sapphire sheet may be very thin. For example, the thickness of a sapphire cover sheet may be less than 300 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 100 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 50 microns thick. In some embodiments, the rear cover 608 is contoured in shape. For example, the rear cover 608 may have a convex curved surface.

FIG. 7 depicts an example exploded view of various modules and subassemblies of the device 100. As shown in FIG. 7, multiple components are configured to be disposed within and/or attached to the housing 601. The exploded view provided in FIG. 7 depicts one example arrangement of the components of the device 100. However, in other embodiments, arrangement, placement, and/or grouping of the subassemblies and the components of the subassemblies may vary.

In the present example, a main cavity of the housing 601 houses an electronics subassembly 720 and the battery 114 of the device. The electronics subassembly 720 includes one or more electrical circuit assemblies for coupling the various electrical components of the device 100 to each other and to power supplied by the battery 114. The electronics subassembly 720 may also include structural elements or components that provide structural rigidity for the electronics subassembly 720 and/or structural mounting or support for other components disposed within the housing 601. As shown in FIG. 7, within the cavity of the housing 601, the speaker 122, the crown module 642, and the battery 114 are all disposed above the electronics subassembly 720. In the present embodiment the top surface of the speaker 122, the crown module 642, and the battery 114 have a substantially similar height. In some embodiments, the speaker 122, the crown module 642, and the battery 114, when assembled in the housing 601, define an area for the display 120 within the cavity. Thus, as shown in FIG. 7, the display 120 may overlay the speaker 122, the crown module 642, and the battery 114, which overlay the electronics subassembly 720.

As shown in FIG. 7, the cover 609 is configured to fit within a corresponding recess formed within the housing 601. In particular, the cover 609 includes a vertical portion having a height that corresponds to the depth of the recess formed within the housing 601. In this example, the device 100 includes a force sensor 705 disposed between the housing 601 and a cover subassembly 704. As described in



more detail below with respect to FIGS. 9 and 10A-B, the force sensor 705 may be configured to detect a force placed on a surface of the cover 609 by detecting a relative deflection between the cover 609 (or cover subassembly 704) and the housing 601. In the present example, the force sensor 705 also forms a gasket or seal between the cover subassembly 704 and the housing 601. In some implementations, the seal is a water-proof or water-resistant seal that helps to prevent water or liquid ingress into the internal cavity of the housing 601. The force sensor 705 may also be used to join the cover subassembly 704 to the housing 601 using an adhesive or film.

In some embodiments, the cover subassembly 704 includes the cover 609 which is disposed above the touch sensor 702 and display 120. In the present example, the touch sensor 702 and the display 120 are attached to each other by an optically clear adhesive layer (OCA). Similarly, an OCA layer is used to attach the touch sensor 702 to the cover 609. Other adhesives or bonding techniques may be used to attach the display 120 and the touch sensor 702 to the cover 609. In some embodiments, the touch sensor 702 is integrated into the display 120 and the display 120 (and integrated touch sensor 702) are attached to the cover 609.

As shown in FIG. 7, the speaker 122 is also disposed within the cavity of the housing 601. The speaker 122 is adapted to mechanically and acoustically interface with a port formed in the side of the housing 601. In some embodiments, the port is configured to prevent a direct path for water or liquid into an acoustic chamber or cavity of the speaker 122. In some embodiments, the device 100 also includes a microphone that is similarly coupled to another port formed in the side of the housing 601. A more detailed description of the speaker 122 and microphone is provided below with respect to the acoustic module of FIG. 20.

In the present example, the haptic device 112 is also disposed within the cavity of the housing 601 proximate to the speaker 122. In some embodiments, the haptic device 112 is rigidly mounted to a portion of the housing 601. A rigid mounting between the housing 601 and the haptic device 112 may facilitate the transmission of vibrations or other energy produced by the haptic device 112 to the user. In the present example, the haptic device 112 includes a moving mass that is configured to oscillate or translate in a direction that is substantially parallel with a rear face of the housing 601. In some implementations, this orientation facilitates the perception of a haptic output produced by the haptic device 112 by a user wearing the device 100. While this configuration is provided as one example, in other implementations, the haptic device 112 may be placed in a different orientation or may be configured to produce a haptic response using a rotating mass or other type of moving mass.

As shown in FIG. 7, the device also includes an antenna subassembly 722. In this example, a portion of the antenna subassembly 722 is disposed within the housing 601 and a portion of the antenna subassembly 722 is disposed within the cover assembly. In some implementations, a portion of the antenna subassembly 722 is disposed relative to a feature formed within the cover 609. An example embodiment is described in more detail below with respect to FIGS. 21A-B.

In the example depicted in FIG. 7, the device 100 also includes a crown module 642 which is disposed in an aperture or hole in the housing 601. When installed, a portion of the crown module 642 is located outside of the housing 601 and a portion of the crown module 642 is disposed within the housing 601. The crown module 642 may be configured to mechanically and/or electrically coop-

erate with the electronics subassembly 720. A more detailed description of an example crown module is provided below with respect to FIGS. 23 and 24A-B. The housing 601 also includes a button 644, which is disposed in an opening of the housing 601 and may be configured to mechanically and/or electrically cooperate with the electronics subassembly 720.

In the example depicted in FIG. 7, a biosensor module 710 is disposed in an opening formed in the rear surface of the housing 601. In some embodiments, the biosensor module 710 includes the rear cover 608 and may also include a chassis or plate that facilitates attachment of the biosensor module 710 to the housing 601. The chassis or plate or the cover sheet 608 may also include features or elements that facilitate a watertight seal between the biosensor module 710 and the housing 601. For example, the rear cover 608 may include a shelf or flange that may be used to form a seal between the biosensor module 710 and the housing 601. As described in more detail below with respect to FIG. 16, the biosensor module 710 may include one or more light sources, one or more photodetectors, and one or more electrodes or conductive elements that are configured to detect and measure a physiological condition or property of the user.

In some embodiments, the rear cover 608 has an edge that protrudes outwardly from the back surface of the housing 601. The rear cover 608 may also have a convex curved area located between the edges of the rear cover 608. The convex curved area of the rear cover 608 may include one or more windows or apertures that provide operational access to one or more internal components located within the housing 601. In some embodiments, the windows have a curvature that matches the curvature of the convex curved area of the rear cover.

2. Example Housing

As described above, a wearable electronic device may include a device body that includes a housing or enclosure shell. As previously described, the housing may function as a chassis that physically integrates the various components of the device. The housing may also form a protective shell or housing for the components and function as a barrier against moisture or debris. In the present examples, the housing is formed as a uni-body, unitary, or single body or component. A single-body construction may be advantageous by providing mounting features directly into the housing, which may reduce space, reduce part count, and increase structural rigidity as compared to some alternative configurations. Additionally, a single-body construction may improve the housing's ability to prevent the ingress of moisture or debris by reducing or eliminating seams or joints between external components.

FIG. 8 depicts an example housing 601 in accordance with some embodiments. In the present example, the housing 601 is formed as a single body or component. As shown in FIG. 8, the housing 601 is formed as a single part or body. The housing 601 may be formed, for example, by machining or shaping a solid or cast blank having the approximate shape of the housing 601. In some implementations, the housing 601 may be configured to provide structural integrity for potentially delicate internal components and also withstand a reasonable impact.

In the present embodiment, the housing 601 is formed as a uni-body, unitary, or single-body construction having a flat bottom portion 801 and a top portion including flange 812. The top portion defines an internal cavity 805, which is surrounded by four sides 802a-d that are integrally formed with the bottom portion 801. The internal cavity 805 can also be described as being defined by the top portion, the four

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sides 802a-d and the bottom portion 801. In this example, the internal cavity 805 has a rectangular (square) shape, although the specific shape may vary with different implementations. In the present example, the four sides 802a-d define a curved side portion of the housing 601 that extends from the bottom portion 801 to the top portion of the housing 601. Each side 802a-d is orthogonal to an adjacent side and each side 802a-d is connected to an adjacent side by a rounded corner. For example, side 802a is orthogonal to two adjacent sides 802b and 802d and is connected to those sides by respective rounded corners. The shape or contour of the rounded corners may correspond to the curvature of the curved portion of the housing 601. Specifically, the curvature of the rounded corners may match or correspond to the curvature of the continuous external surface formed by the housing 601 and the cover 609, as described above with respect to FIG. 6.

The sides 802a-d may vary in thickness in order to provide the structural rigidity for the device. In general, areas of high stress may have an increased material thickness as compared to areas of low stress, which may have a reduced material thickness. In particular, portions of the sides 802a-d near the bottom portion 801 may have an increased thickness as compared to portions of the sides 802a-d located further away from the bottom portion 801. This configuration may improve the structural rigidity and overall stiffness of the housing 601.

As shown in FIG. 8, one or more mounting features may be formed directly into the housing 601, which may reduce the number of parts and also enhance the structural integrity of the device. As shown in FIG. 8, receiving features 623, 624 may be formed as channels or openings that are configured to receive an end of a band (e.g., a lug) having a mating feature. As described above with respect to FIG. 5, the receiving features 623, 624 may be standardized and configured to work with a system of interchangeable components. Forming the receiving features 623, 624 directly into the housing 601 may reduce parts and also facilitate structural rigidity of the device.

In the example depicted in FIG. 8, the housing 601 can be described as having two ends (a first end and a second end opposite the first end), and a first side and a second side opposite the first side, the sides being continuous with the ends. In this example, the first and second ends and the first and second sides having an outwardly curved three-dimensional shape. In this example, the receiving feature 623 is formed from a first groove situated in the first end. Similarly, the receiving feature 624 is formed from a second groove situated in the second end. In the present example the grooves have openings at the interface of the first and second sides and first and second ends. As shown in FIG. 8 the groove also has an inwardly curved concave three-dimensional shape with an undercut feature. For example, the middle portion of the groove of receiving features 623, 624 may have a width that is greater than the opening of the receiving features 623, 624. In some embodiments, the upper portion of the housing overhangs the lower portion of the housing at the groove opening. In the example depicted in FIG. 8, the groove is cut into a solid portion of the housing such that the groove forms a continuous interior shape.

The geometry of the receiving features may be located with respect to other features or components of the device. In the example depicted in FIG. 8, at least a portion of the groove of the receiving features 623, 624 may be disposed underneath the cover (item 609 of FIGS. 6-7). With respect to FIG. 6, the groove of the receiving features 623, 624 is located underneath the opening for the cover, which is

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defined by the sealing ledge 810 and flange 812 formed in the upper portion of the housing 601. In some embodiments, the length of the groove extends further than the width of the opening configured to receive the cover (and thus the cover, when assembled). In some embodiments, the grooves are formed at an angle relative to the centerline of the housing. In some cases, the angle is approximately 5 degrees. In some embodiments, the groove is located underneath the centerline of the housing 601. In some embodiments, the groove is angled upward toward the top of the housing 601 and inward toward the center of the housing 601. The groove may angle upward and cross the centerline of the housing. In some cases, the groove crosses the vertical centerline of the housing 601.

In the present embodiment, the housing 601 also includes an aperture 821 formed into the side 802c of the housing 601 for attaching a crown or crown module (item 642 of FIGS. 6-7). In some embodiments, the aperture 821 for the crown is offset upwardly from the centerline of the housing 601. In some embodiments, the aperture 821 for the crown is positioned such that an upper portion of a crown (when installed) is higher than the interface of cover 609 and housing 601. With respect to FIG. 6, the interface may correspond to the upper edge of the flange 812.

The housing 601 also includes an opening 822 formed into the side 802c of the housing 601 for attaching the button (item 644 of FIGS. 6-7). In some embodiments, the aperture 821 for the crown and the opening 822 for the button are disposed with the length defined by a flat part of the cover. In some embodiments, the aperture 821 for the crown is disposed above the centerline of the housing 601 and the opening 822 for the button is disposed below the centerline of the housing 601. In some embodiments, the aperture 821 for the crown and the opening 822 for the button are disposed on a curved surface of the housing 601. The housing 601 may also include various other internal features, including threaded features and bosses, for attaching other internal components of the device.

In some cases, the housing 601 may be formed as a single-piece or integral enclosure shell to enhance the structural rigidity and/or liquid-sealing properties of the device. As described above with respect to FIGS. 6 and 7, the housing 601 may be integrated with a cover (e.g., crystal) and other external components to provide a substantially sealed housing. In the present embodiment, the housing 601, includes a sealing ledge 810 formed around the perimeter of the main cavity 805 formed within the housing 601. In some embodiments, the sealing ledge 810 (and thus the cover when installed) is located in the center of the housing 601. The sealing ledge 810 may be defined by a substantially flat portion 811 that is adapted to form a seal between the housing 601 and another component (e.g., the force sensor 705 or cover 609 of FIGS. 6-7). The sealing ledge 810 may be formed at a depth that is substantially similar or corresponds to the thickness of the mating cover.

As shown in FIG. 8, the sealing ledge 810 may also include flange 812 that protrudes from the flat portion and forms a continuous surface with the side walls 802a-d. In some cases, the flange 812 is configured to cooperate with the cover (item 609 of FIGS. 6-7) to form a substantially continuous surface. In some implementations, the sides 802a-d and the cover or crystal are configured to cooperate or mechanically interface to improve the strength and the water sealing properties of the device.

As also shown in FIG. 8, an opening or aperture 815 may be formed in the bottom portion 801 of the housing 601. In some embodiments, the opening or aperture 815 is located



at the center of the housing 601. As described above with respect to FIG. 7, the aperture 815 may be used to integrate a sensor array or other module used to collect measurements that may be used to compute a health metric or other health-related information. The present embodiment may be advantageous by integrating multiple components in a single opening 815, which may facilitate a water-proof or water-resistant property of the device. Additionally, by integrating a sensor array into a module that attaches via the opening 815, same housing 601 may be used with a variety of sensing configurations or arrays. For example, the number or sensors or components may be increased or decreased without modifying the housing 601. This may allow for flexibility in the product development and may facilitate upgrades as new sensing configurations are available.

As previously discussed above with respect to FIGS. 6-7, the housing 601 may also be configured to serve as a protective housing for one or more acoustic elements, such as a microphone or speaker. Additionally, in some embodiments, the housing 601 may also be configured to inhibit the ingress of foreign particulate or moisture. In particular, the housing 601 may include a speaker port having orifices 831, 832 that are configured to transmit acoustic signals but also prevent the ingress of liquid or other foreign particulate. In the present example, the speaker port includes orifices 831, 832 that are offset with respect to an acoustic chamber or cavity to prevent the direct ingress of liquid into the speaker subassembly or acoustic module. In the present example, a shielding or umbrella portion of the housing, which is substantially free of openings, is formed between the orifices 831, 832, which helps to prevent the direct ingress of liquid. Similarly, the housing 601 includes a microphone port having orifices 833, 834 that are offset from a corresponding acoustic chamber or cavity to prevent the direct ingress of liquid into the microphone subassembly or acoustic module.

In the example depicted in FIG. 8, the orifices 831, 832 of the speaker port are located on one side of the aperture 821 for the crown and the orifices 833, 834 for the microphone are located on the other side of the aperture 821. Both the orifices 831, 832 of the speaker port and the orifices 833, 834 for the microphone are located on a curved portion of the housing 601.

3. Example Force Sensor and Touch Sensor

As discussed previously, a wearable electronic device may include one or more sensors for detecting the location and force of a touch. For the purposes of the following description of the force sensor and touch sensor, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100 including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a force sensor and a touch sensor may be disposed relative to the display of a wearable electronic device for to form a touch-sensitive surface. The following description is provided with respect to individual force and touch sensors that may be used to determine the force and location of a touch, respectively. However, in some embodiments, a single integrated sensor may be used to detect both the force and location of a touch on the device.

In one embodiment, an output from a force sensor may be combined with a touch sensor to provide both location and force of a single touch or of multiple touches on the surface of a device. In an alternative embodiment, a hybrid or integrated force and touch sensor may be used to sense both touch force and location of a single touch or of multiple touches. In either embodiment, by sensing both the force and

location of a touch, multiple types of user input may be generated and interpreted. In one example, a first touch may be correlated with a first force and a first touch location or gesture. Based on the magnitude of the force, the first touch may be interpreted as a first type of input or command. A second touch may be sensed as having a second, different force and a similar location or gesture as the first touch. Based in part on the magnitude of the second force, the second touch may be interpreted as a second type of input or command. Thus, a force sensor (alone or in combination with another touch sensor) may be used to produce different responses or outputs depending on the force of the touch.

The one or more force sensors may be formed from or may be implemented as one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on a deflection of the surface, such as the cover glass.

By way of example, the force sensor may include a capacitive force sensor, which may be formed from one or more capacitive plates or conductive electrodes that are separated by a compressible element or other compliant member. As a force is applied to a surface of the device, the compressible element may deflect resulting in a predictable change in the capacitance between the plates or electrodes. In some implementations, a capacitive force sensor may be formed from transparent materials and disposed over the display. In other implementations, a capacitive force sensor may be formed from non-transparent materials and disposed beneath or around the perimeter of a display.

FIG. 9 depicts a detail cross-sectional view of a portion of a force sensor 900 that may be arranged around the perimeter of a display 120. As shown in FIG. 9, a force-sensing structure 901 of the force sensor 900 may be disposed beneath the cover 609 and along the side of an edge or the perimeter of the display 120. In this example, the force sensor 900 is configured to detect and measure the force of a touch on the surface 911 of the cover 609. In the present embodiment, a first capacitive plate 902 is fixed with respect to the cover 609. A second, lower capacitive plate 904 is fixed with respect to the housing 601 and may be disposed on a shelf or mounting surface located along the perimeter of the device. The first capacitive plate 902 and the second capacitive plate 904 are separated by a compressible element 906.

In the configuration depicted in FIG. 9, a touch on the surface 911 of the device may cause a force to be transmitted through the cover 609 of the device and to the force sensor 900. In some cases, the force causes the compressible element 906 to compress, thereby bringing the first capacitive plate 902 and the second capacitive plate 904 closer together. The change in distance between the first and second capacitive plates 902, 904 may result in a change of capacitance, which may be detected and measured. For example, in some cases, a force-sensing circuit may measure this change in capacitance and output a signal that corresponds to the measurement. A processor, integrated circuit or other electronic element may correlate the circuit output to an estimate of the force of the touch. Although the term "plate" may be used to describe certain elements, such as the capacitive plates or conductive electrodes, it should be

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appreciated that the elements need not be rigid but may instead be flexible (as in the case of a trace or flex).

FIG. 10A depicts an example configuration of the force sensor 1000 having four individual force-sensing structures 1001a-d arranged around the perimeter of a display in a device. For the sake of clarity, the crystal, display, and other elements of the device are omitted from the depiction of FIG. 10A. Each of the force-sensing structures 1001a-d may be formed from a pair of capacitive plates separated by a compressible element. Additionally, each force-sensing structure 1001a-d may be separated by a small gap at or near the corners of the opening in the housing 601. In the example depicted in FIG. 10A, the four individual force-sensing structures 1001a-d may each be operatively coupled to force-sensing circuitry that is configured to detect a change in the capacitance of each force-sensing structure 1001a-d. Using the example arrangement depicted in FIG. 10A, the approximate location of the touch may be determined by comparing the relative change in capacitance of each force-sensing structure 1001a-d. For example, a change in capacitance of structure 1001b that is larger as compared to a change in capacitance of structure 1001d may indicate that the touch is closer to structure 1001b. In some embodiments, the degree of the difference in the change in capacitance may be used to provide a more accurate location estimate.

While the configuration shown in FIG. 10A depicts the force-sensing structures as individual elements separated by a small gap, in some embodiments, the force-sensing structure may be formed as a single continuous piece. FIG. 10B depicts a force sensor 1050 formed as a single force-sensing structure 1051 formed as a continuous part along the perimeter of the display. Similar to the example described above, the force-sensing structure 1051 may be operatively coupled to force sensing circuitry that is configured to detect a change in the capacitance of one or more capacitive elements of the force-sensing structure 1051. While the force-sensing structure 1051 is formed as a continuous structure, there may be multiple sensing elements (e.g., capacitive plates) that are disposed within the structure at different locations, and which may be configured to detect deflection or compression of the structure over a portion of entire area of the force-sensing structure 1051. In some embodiments, the force-sensing structure 1051 may also function as a seal or gasket to prevent ingress of moisture or other foreign contaminants into the main cavity of the housing. Additionally, the force-sensing structure 1051 may be integrated with one or more sealing or adhesive layers that also function as a barrier for foreign contaminants.

As mentioned previously, the force sensor may additionally or alternatively include a strain-based sensing configuration. The strain-based sensing configuration may include, for example, a charge-based or resistive sensor configuration. FIG. 11 depicts a cross-sectional view of a device having an example force sensor 1100 that uses one or more force-sensitive films to detect and measure the force of a touch on a surface 1111 of the cover 609. In this example, the force sensitive film 1102 and 1104 are formed from a transparent material and are disposed relative to a viewable portion of the display 120. As shown in FIG. 11, the force sensor 1100 includes a first force-sensitive film 1102 and a second force-sensitive film 1104 that are separated by one or more intermediate layers 1106. The force-sensitive films 1102, 1104 may be configured to produce different electrical outputs in response to a strain or deflection of the cover 609. In some cases, the intermediate layer 1106 is compressible to allow the first force-sensitive film 1102 to deflect with respect to the second force-sensitive film 1104. In other

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cases, the intermediate layer 1106 may not be compressible and the first force-sensitive film 1102 deflects in a predictable manner with respect to the second force-sensitive film 1104. While FIG. 11 depicts an example force sensor 1100 having two force-sensitive films, alternative embodiments may include only a single force-sensitive film or, alternatively, include more than two force-sensitive films.

In general, a transparent force-sensitive film may include a compliant material that exhibits an electrical property that is variable in response to deformation or deflection of the film. The transparent force-sensitive film may be formed from a piezoelectric, piezo-resistive, resistive, or other strain-sensitive materials. Transparent resistive films can be formed by coating a substrate with a transparent conductive material. Potential transparent conductive materials include, for example, polyethyleneoxythiophene (PEDOT), indium tin oxide (ITO), carbon nanotubes, graphene, silver nanowire, other metallic nanowires, and the like. Potential substrate materials include, for example, glass or transparent polymers like polyethylene terephthalate (PET) or cycloolefin polymer (COP). Typically, when a piezo-resistive or resistive film is strained, the resistance of the film changes as a function of the strain. The resistance can be measured with an electrical circuit. In this way, a transparent piezo-resistive or resistive film can be used in a similar fashion as a strain gauge.

If transparency is not required, then other film materials may be used, including, for example, Constantan and Karma alloys for the conductive film and a polyimide may be used as a substrate. Nontransparent applications include force sensing on track pads or the back of display elements. In general, transparent and non-transparent force-sensitive films may be referred to herein as "force-sensitive films" or simply "films."

In some embodiments, the force-sensitive film is patterned into an array of lines, pixels, or other geometric elements herein referred to as film elements. The regions of the force-sensitive film or the film elements may also be connected to sense circuitry using electrically conductive traces or electrodes. FIG. 12 depicts a cross-sectional view of a device having a strain-based force sensor 1200 formed from one or more strain pixel elements 1202 and 1204 separated by intermediate layer 1206. Each of the pixel elements 1202, 1204 may be separated by a gap 1210. In the present example, each pixel element 1202, 1204 may exhibit a measurable change in an electrical property in response to a force being applied to the device. By way of example, as a force is applied to a surface 1211 on the cover 609, one or more of the pixel elements 1202, 1204 is deflected or deformed. Sense circuitry, which is in electrical communication with the one or more pixel elements 1202, 1204, may be configured to detect and measure the change in the electrical property of the film due to the deflection. Based on the measured electrical property of the pixel elements 1202, 1204, an estimated amount of force can be computed. In some cases, the estimated force may represent the magnitude of a touch on the surface 1211 of the device, and be used as an input to a graphical user interface or other element of the device. Additionally, in some embodiments, the relative strain of the individual pixel elements may be compared to estimate a location of the touch. While FIG. 12 depicts an example force sensor 1200 having two layers of pixel elements, alternative embodiments may include only a single layer of pixel elements or, alternatively, include more than two layers of pixel elements.

The pixel elements 1202, 1204 may be specifically configured to detect strain along one or more directions. In some



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cases, each pixel element 1202, 1204 includes an array of traces generally oriented along one direction. This configuration may be referred to as a piezo-resistive or resistive strain gauge configuration. In general, in this configuration the force-sensitive-film is a material whose resistance changes in response to strain. The change in resistance may be due to a change in the geometry resulting from the applied strain. For example, an increase in length combined with decrease in cross-sectional area may occur in accordance with Poisson's effect. The change in resistance may also be due to a change in the inherent resistivity of the material due to the applied strain. For example, the applied strain may make it easier or harder for electrons to transition through the material. The overall effect is for the total resistance to change with strain due to the applied force.

Further, in a piezo-resistive or resistive strain gauge configuration, each pixel may be formed from a pattern of the force-sensitive-film, aligned to respond to strain along a particular axis. For example, if strain along an x-axis is to be measured, the pixel should have a majority of its trace length aligned with the x-axis. By way of example, FIG. 13A depicts a pixel element 1302 having traces that are generally oriented along the x-axis and may be configured to produce a strain response that is substantially isolated to strain in the x-direction. Similarly, FIG. 13B depicts a pixel element 1304 having traces that are generally oriented along the y-axis and may be configured to produce a strain response that is substantially isolated to strain in the y-direction.

In some embodiments, the force-sensitive film may be formed from a solid sheet of material and is in electrical communication with a pattern of electrodes disposed on one or more surfaces of the force-sensitive film. The electrodes may be used, for example, to electrically connect a region of the solid sheet of material to sense circuitry. This configuration may be referred to as a piezo-strain configuration. In this configuration, the force-sensitive film may generate a charge when strained. The force-sensitive film may also generate different amounts of charge depending on the degree of the strain. In some cases, the overall total charge is a superposition of the charge generated due to strain along various axes.

As mentioned previously, a force sensor may be combined with a touch sensor that is configured to detect and measure the location of a touch on the surface of the device. FIG. 14A depicts a simplified schematic representation of an example mutual capacitance touch sensor. As shown in FIG. 14A, a touch sensor 1430 may be formed by an array of nodes 1402 formed at the intersection of an array of drive lines 1404 and sense lines 1406. In this example, stray capacitance  $C_{stray}$  may be present at each node 1402 (although FIG. 14A depicts only one  $C_{stray}$  for one column for purposes of simplifying the figure). In the example of FIG. 14A, AC stimuli  $V_{stim}$  1414,  $V_{stim}$  1415 and  $V_{stim}$  1417 can be at different frequencies and phases. Each stimulation signal on a row can cause a charge  $Q_{sig} = C_{sig} \times V_{stim}$  to be injected into the columns through the mutual capacitance present at the affected nodes 1402. A change in the injected charge ( $Q_{sig\_sense}$ ) can be detected when a finger, palm or other object is present at one or more of the affected nodes 1402.  $V_{stim}$  signals 1414, 1415 and 1417 can include one or more bursts of sine waves. Note that although FIG. 14A illustrates rows 1404 and columns 1406 as being substantially perpendicular, they need not be aligned, as described above. Each column 1406 may be operatively coupled to a receive channel of a charge-monitoring circuit.

FIG. 14B depicts a side view of an exemplary node in a steady-state (no touch) condition according to examples of

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the disclosure. In FIG. 14B, electric field lines 1408 between a column 1406 and a row 1404 separated by dielectric 1410 is shown at node 1402.

FIG. 14C depicts a side view of an exemplary pixel in a dynamic (touch) condition. An object such as finger 1412 can be placed near node 1402. Finger 1412 can be a low-impedance object at signal frequencies, and can have an AC capacitance  $C_{finger}$  from the column trace 1406 to the body. The body can have a self-capacitance to ground  $C_{body}$  of about 200 pF, where  $C_{body}$  can be much larger than  $C_{finger}$ . If finger 1412 blocks some electric field lines 1408 between row and column electrodes (those fringing fields that exit the dielectric 1410 and pass through the air above the row electrode), those electric field lines can be shunted to ground through the capacitance path inherent in the finger and the body, and as a result, the steady state signal capacitance  $C_{sig}$  can be reduced by  $DC_{sig}$ . In other words, the combined body and finger capacitance can act to reduce  $C_{sig}$  by an amount  $DC_{sig}$  (which can also be referred to herein as  $C_{sig\_sense}$ ), and can act as a shunt or dynamic return path to ground, blocking some of the electric field lines as resulting in a reduced net signal capacitance. The signal capacitance at the pixel becomes  $C_{sig} - DC_{sig}$ , where  $DC_{sig}$  represents the dynamic (touch) component. Note that  $C_{sig} - DC_{sig}$  may always be nonzero due to the inability of a finger, palm or other object to block all electric fields, especially those electric fields that remain entirely within the dielectric material. In addition, it should be understood that as finger 1412 is pushed harder or more completely onto the touch sensor, finger 1412 can tend to flatten, blocking more and more of the electric fields lines 1408, and thus  $DC_{sig}$  may be variable and representative of how completely finger 1412 is pushing down on the panel (i.e., a range from "no-touch" to "full-touch").

Additionally or alternatively, the touch sensor may be formed from an array of self-capacitive pixels or electrodes. FIG. 15A depicts an example touch sensor circuit corresponding to a self-capacitance touch pixel electrode and sensing circuit. Touch sensor circuit 1509 can have a touch pixel electrode 1502 with an inherent self-capacitance to ground associated with it, and also an additional self-capacitance to ground that can be formed when an object, such as finger 1512, is in proximity to or touching the touch pixel electrode 1502. The total self-capacitance to ground of touch pixel electrode 1502 can be illustrated as capacitance 1504. Touch pixel electrode 1502 can be coupled to sensing circuit 1514. Sensing circuit 1514 can include an operational amplifier 1508, feedback resistor 1516, feedback capacitor 1510 and an input voltage source 1506, although other configurations can be employed. For example, feedback resistor 1516 can be replaced by a switch capacitor resistor. Touch pixel electrode 1502 can be coupled to the inverting input of operational amplifier 1508. An AC input voltage source 1506 can be coupled to the non-inverting input of operational amplifier 1508. Touch sensor circuit 1509 can be configured to sense changes in the total self-capacitance 1504 of touch pixel electrode 1502 induced by finger 1512 either touching or in proximity to the touch sensor panel. Output 1520 can be used by a processor to determine a presence of a proximity or touch event, or the output can be inputted into a discreet logic network to determine the presence of a touch or proximity event.

FIG. 15B depicts an example self-capacitance touch sensor 1530. Touch sensor 1530 can include a plurality of touch pixel electrodes 1502 disposed on a surface and coupled to sense channels in a touch controller, can be driven by stimulation signals from the sense channels through drive/sense interface 1525, and can be sensed by the sense

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channels through the drive/sense interface 1525 as well. After touch controller has determined an amount of touch detected at each touch pixel electrode 1502, the pattern of touch pixels in the touch screen panel at which touch occurred can be thought of as an “image” of touch (e.g., a pattern of fingers touching the touch screen). The arrangement of the touch pixel electrodes 1502 in FIG. 15B is provided as one example; however, the arrangement and/or the geometry of the touch pixel electrodes may vary depending on the embodiment.

As previously mentioned, a force sensor may be implemented alone or in combination with another type of touch sensor to sense both touch force and touch location, which may enable more sophisticated user touch input than using touch location alone. For example, a user may manipulate a computer-generated object on a display using a first type of interaction using a relatively light touch force at a given touch location. The user may also interact with the object using a second type of interaction by using a relatively heavy or sharper touch force at the given location. As one specific example, a user may manipulate or move a computer-generated object, such as a window, using a relatively light touch force. Additionally or alternatively, the user may also select or invoke a command associated with the window using a relatively heavy or sharper touch force. In some cases, multiple types of interactions may be associated with multiple amounts of touch force.

Additionally, it may be advantageous for the user to be able to provide an analog input using a varying amount of force. A variable, non-binary input may be useful for selecting within a range of input values. The amount of force may, in some cases, be used to accelerate a scrolling operation, a zooming operation, or other graphical user interface operation. It may also be advantageous to use the touch force in a multi-touch sensing environment. In one example, the force of a touch may be used to interpret a complex user input performed using multiple touches, each touch having a different magnitude or degree of force. As a specific but non-limiting example, touch and force may be used in a multi-touch application that allows the user to play a varying tone or simple musical instrument using the surface of the device. In such a housing, the force of each touch may be used to interpret a user's interaction with the buttons or keys of a virtual instrument. Similarly, the force of multiple touches can be used to interpret a user's multiple touches in a game application that may accept multiple non-binary inputs at different locations.

#### 4. Sensor or Biosensor Module

As described above with respect to FIG. 2, a wearable electronic device may include one or more sensors that can be used to calculate a health metric or other health-related information. For the purposes of the following description of the biosensor module, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100 including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a wearable electronic device may function as a wearable health assistant that provides health-related information (whether real-time or not) to the user, authorized third parties, and/or an associated monitoring device. The wearable health assistant may be configured to provide health-related information or data such as, but not limited to, heart rate data, blood pressure data, temperature data, blood oxygen saturation level data, diet/nutrition information, medical reminders, health-related tips or informa-

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tion, or other health-related data. The associated monitoring device may be, for example, a tablet computing device, phone, personal digital assistant, computer, and the like.

In accordance with some embodiments, the electronic device can be configured in the form of a wearable electronic device that is configured or configurable to provide a wide range of functionality. As described above with respect to FIG. 2, the wearable electronic device 100 may include a processing units 102 coupled with or in communication with a memory 104, one or more communications channels 108, output devices such as a display 120 and speaker 122, one or more input components 106, and other modules or components. An example wearable electronic device 100 may be configured to provide or calculate information regarding time, health information, biostatistics, and/or status to externally connected or communicating devices and/or software executing on such devices. The device 100 may also be configured to send and receive messages, video, operating commands, and other communications.

With reference to FIG. 16, an example device 100 may include various sensors for measuring and collecting data that may be used to calculate a health metric or other health-related information. As one example, the wearable communication device can include an array of light sources 1611-1613 and a detector 1614 that are configured to function as an optical sensor or sensors. In one example, an optical sensor or sensors may implemented as a pairing of one or more light sources 1611-1613 and the detector 1614. In one example implementation, the detector 1614 is configured to collect light and convert the collected light into an electrical sensor signal that corresponds to the amount of light incident on a surface of the detector 1614. In one embodiment, the detector may be a photodetector, such as a photodiode. In other embodiments, the detector 1614 may include a phototube, photosensor, or other light-sensitive device.

In some cases, the one or more optical sensors may operate as a photoplethysmography (PPG) sensor or sensors. In some instances, a PPG sensor is configured to measure light and produce a sensor signal that can be used to estimate changes in the volume of a part of a user's body. In general, as light from the one or more light sources passes through the user's skin and into the underlying tissue, some light is reflected, some is scattered, and some light is absorbed, depending on what the light encounters. The light that is received by the detector 1614 may be used to generate a sensor signal, which may be used to estimate or compute a health metric or other physiological phenomena.

The light sources may operate at the same light wavelength range, or the light sources can operate at different light wavelength ranges. As one example, with two light sources, one light source may transmit light in the visible wavelength range while the other light source can emit light in the infrared wavelength range. In some cases, a modulation pattern or sequence may be used to turn the light sources on and off and sample or sense the reflected light. With reference to FIG. 16, the first light source 1611 may include, for example, a green LED, which may be adapted for detecting blood perfusion in the body of the wearer. The second light source 1612 may include, for example, an infrared LED, which may be adapted to detect changes in water content or other properties of the body. The third 1613 light source may be a similar type or different types of LED element, depending on the sensing configuration.

The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics, including, without limitation, a heart rate, a respiration rate, blood oxygenation level,



a blood volume estimate, blood pressure, or a combination thereof. In some instances, blood may absorb light more than surrounding tissue, so less reflected light will be sensed by the detector of the PPG sensor when more blood is present. The user's blood volume increases and decreases with each heartbeat. Thus, in some cases, a PPG sensor may be configured to detect changes in blood volume based on the reflected light, and one or more physiological parameters of the user may be determined by analyzing the reflected light. Example physiological parameters include, but are not limited to, heart rate, respiration rate, blood hydration, oxygen saturation, blood pressure, perfusion, and others.

While FIG. 16 depicts one example embodiment, the number of light sources and/or detectors may vary in different embodiments. For example, another embodiment may use more than one detector. Another embodiment may also use fewer or more light sources than are depicted in the example of FIG. 16. In particular, in the example depicted in FIG. 16, the detector 1614 is shared between multiple light sources 1611-1613. In one alternative embodiment, two detectors may be paired with two corresponding light sources to form two optical sensors. The two sensors (light source/detector pairs) may be operated in tandem and used to improve the reliability of the sensing operation. For example, output of the two detectors may be used to detect a pulse wave of fluid (e.g., blood) as it passes beneath the respective detectors. Having two sensor readings taken at different locations along the pulse wave may allow the device to compensate for noise created by, for example, movement of the user, stray light, and other effects.

In some implementation, one or more of the light sources 1611-1613 and the detector 1614 may also be used for optical data transfer with a base or other device. For example, the detector 1614 may be configured to detect light produced by an external mating device, which may be interpreted or translated into a digital signal. Similarly, one or more of the light sources 1611-1613 may be configured to transmit light that may be interpreted or translated into a digital signal by an external device.

Returning to FIG. 16, the device 100 may also include one or more electrodes to measure electrical properties of the user's body. In this example, a first electrode 1601 and second electrode 1602 are disposed on the rear face of the device 100. The first 1601 and second 1602 electrodes may be configured to make contact with the skin of the user's wrist when the device is being worn. As shown in FIG. 16, a third electrode 1603 and fourth electrode 1604 may be disposed along a periphery of the device body 610. In the configuration of FIG. 16, the third 1603 and fourth 1604 electrodes are configured to come into contact with the skin of the user's other hand (that is not wearing the device 100). For example, the third 1603 and fourth 1604 electrodes may be contacted when the user pinches the device 100 between two digits (e.g., a forefinger and thumb).

FIG. 16 depicts one example arrangement of electrodes. However, in other embodiments, one or more of the electrodes may be placed in locations that are different than the configuration of FIG. 16. For example, one or more electrodes may be placed on a top surface or other surface of the device 100. Additionally, fewer electrodes or more electrodes may be used to contact the user's skin, depending on the configuration.

Using the electrodes of the device, various electrical measurements may be taken, which may be used to compute a health metric or other health-related information. By way of example, the electrodes may be used to detect electrical activity of the user's body. In some cases, the electrodes may

be configured to detect electrical activity produced by the heart of the user to measure heart function or produce an electrocardiograph (ECG). As another example, the electrodes of the device may be used to detect and measure conductance of the body. In some cases, the measured conductance may be used to compute a galvanic skin response (GSR), which may be indicative of the user's emotional state or other physiological condition. By way of further example, the electrodes may also be configured to measure other health characteristics, including, for example, a body fat estimate, body or blood hydration, and blood pressure.

In some embodiments, the optical sensors and electrodes discussed above with respect to FIG. 16 may be operatively coupled to sensing circuitry and the processing units 102 to define a health monitoring system. In this capacity, the processing units 102 may be any suitable type of processing device. In one embodiment, the processing units 102 include a digital signal processor. The processing units 102 may receive signals from the optical sensor(s) and/or electrodes and process the signals to correlate the signal values with a physiological parameter of the user. As one example, the processing units 102 can apply one or more demodulation operations to the signals received from the optical sensor. Additionally, the processing units 102 may control the modulation (i.e., turning on and off) of the light sources according to a given modulation pattern or sequence. The processing units 102 may also be used to calculate one or more biometrics or other health related information.

In some implementations, the wearable electronic device may also receive sensor data or output from an external device. For example, an external mobile device having a global positioning system (GPS) may relay location information to the wearable device, which may be used to calibrate an activity metric, such as a pedometer or distance calculator. Similarly, sensor output of the wearable electronic device may be transmitted to an external device to compute health-related information. For example, output from an accelerometer in the wearable electronic device may be used to determine a body position or gesture, which may be relayed to an external device and used to compute health-related information, such as activity level.

In some embodiments, some or all of the biosensors may be integrated into a module that is separate from and attached to the housing 601 of the device 100. As described above with respect to FIG. 6, in some embodiments, the biosensors are disposed relative to or attached to a rear cover 608 that is formed from an optically transparent material and is configured to be positioned with the opening of the housing 601. In some embodiments, the rear cover 608 is disposed completely within the area of the cover so that the two components completely overlap when viewed from above. In some embodiments, the rear cover 608 has an edge that protrudes outwardly from the back surface of the housing 601. In some embodiments, an edge of the rear cover 608 extends past a flat portion of the back surface of the housing 601. The rear cover 608 may also have a convex, curved outer contour. The rear cover 608 may have a convex shape that is located within the center and surrounded by the edges of the rear cover 608. The convex curved area of the rear cover 608 may include one or more windows or apertures that provide operational access to one or more internal components located within the housing. For example, the rear cover 608 may include an array of windows, each window including an aperture or opening for a respective light source 1611-1613 and/or the detector 1614. In some embodiments, the windows have a curvature

that matches the curvature of the convex curved area of the rear cover 608. In some embodiments, rear cover 608 includes a chamfered edge and a curved bottom surface, the windows being disposed within the curved surface. In some embodiments, two openings of the rear cover 608 are located along a first axis (e.g., an x-axis) and two openings are located along a second axis (e.g., a y-axis) that is transverse to the first axis.

#### 5. Example Wireless Communications with External Devices

A wearable electronic device may include a functionality for performing wireless communications with an external device. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, the wireless communications are performed in accordance with a Near Field Communications (NFC) protocol. The communication may include an identification protocol and a secured data connection that can be used to identify the user, authorize activity, perform transactions, or conduct other aspects of electronic commerce.

FIG. 17 depicts an example system 1700 including a device 100 that is located proximate to a station 1710. The station 1710 may include a variety of devices, including, without limitation, a payment kiosk, a vending machine, a security access point, a terminal device, or other similar device. In some cases, the station 1710 is incorporated into a larger system or device. For example, the station 1710 may be incorporated into a security gate of a building or a payment center for a vending system.

As shown in FIG. 17, the device 100 is a wearable electronic device that may be placed proximate to the station 1710. In this example, a second device 1720 is carried by a user, and may also be placed proximate to the station 1710. In some embodiments, the device 100 and/or the second device 1720 includes a radio-frequency identification (RFID) system that is configured to enable one-way or two-way radio-frequency (RF) communications with the station 1710. The one- or two-way communication may include an identification of the device 100 and the station 1710 to initiate a secured data connection between the two devices. The secured data connection may be used to authorize a transaction between the user and an entity that is associated with the station 1710.

In some embodiments, the user may initiate a communication with the station 1710 by placing the device 100 near an active region on the station 1710. In some implementations, the station 1710 is configured to automatically detect the presence of the device 100 and initiate an identification process or routine. The RFID system of the device may include a unique identifier or signature that may be used to authenticate the identity of the user. As previously mentioned, the identification process or routine may be used to establish a secure data connection between the device 100 and the station 1710. The secure data connection may be used to authorize a purchase or download of data to or from the device 100. In some cases, the secure data connection may be used to authorize the transfer of funds from a credit card or financial institution in exchange for a product that is associated with the station 1710. Other transactions or forms of electronic commerce may also be performed using the wireless communication between the device 100 and the station 1710.

#### 6. Example Wireless Power System

As discussed above, a wearable electronic device may include an internal battery that is rechargeable using an external power source. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

One challenge associated with small devices is that it may be difficult to incorporate an electrical port for coupling the device to an external power source. Because wearable electronic devices have limited space for an external connector, it may be advantageous to electrically couple to a device without a cable or external connector. In at least some embodiments, the wearable electronic device described herein may be configured to operate as a receiver in a wireless power transfer system.

A wireless power transfer system, one example of which is an inductive power transfer system, typically includes a power-transmitting structure to transmit power and a power-receiving structure to receive power. In some examples, a power-receiving electronic device includes or otherwise incorporates an inductive power-receiving element configured to receive wireless power and/or charge one or more internal batteries. Similarly, a charging device may include or otherwise incorporate an inductive power-transmitting element configured to wirelessly transmit power to the power-receiving electronic device. The charging device may be configured as a base or dock on which the power-receiving electronic device rests or to which it physically connects in some embodiments. In other embodiments, the charging device may be proximate the electronic device but not necessarily touching or physically coupled.

In many examples, the battery-powered electronic device may be positioned on an external surface of the power-transmitting device, otherwise referred to as a dock. In these systems, an electromagnetic coil within the dock (e.g., transmit coil) may produce a time-varying electromagnetic flux to induce a current within an electromagnetic coil within the electronic device (e.g., receive coil). In many examples, the transmit coil may transmit power at a selected frequency or band of frequencies. In one example the transmit frequency is substantially fixed, although this is not required. For example, the transmit frequency may be adjusted to improve inductive power transfer efficiency for particular operational conditions. More particularly, a high transmit frequency may be selected if more power is required by the electronic device and a low transmit frequency may be selected if less power is required by the electronic device. In other examples, a transmit coil may produce a static electromagnetic field and may physically move, shift, or otherwise change its position to produce a spatially-varying electromagnetic flux to induce a current within the receive coil.

The electronic device may use the received current to replenish the charge of a rechargeable battery or to provide power to operating components associated with the electronic device. Thus, when the electronic device is positioned on the dock, the dock may wirelessly transmit power at a particular frequency via the transmit coil to the receive coil of the electronic device.

A transmit coil and receive coil may be disposed respectively within housings of the dock and electronic device so as to align along a mutual axis when the electronic device is placed on the dock. If misaligned, the power transfer efficiency between the transmit coil and the receive coil may



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decrease as misalignment increases. Accordingly, in many examples, the wireless power transfer system may include one or more alignment assistance features to effect alignment of the transmit and receive coils along the mutual axis.

FIG. 18 depicts a front perspective view of an example wireless power transfer system 1800 in an unmated configuration. The illustrated embodiment shows an inductive power transmitter dock 1802 that is configured to couple to and wirelessly transmit power to an inductive power receiver accessory, in this case device 100. The wireless power transfer system 1800 may include one or more alignment assistance features to effect alignment of the device 100 with the dock 1802 along a mutual axis. For example, the housings of the dock 1802 and the device 100 may assist with alignment. In one implementation, a portion of the housing of the device 100 may engage and/or interlock with a portion of the housing of the dock 1802 in order to effect the desired alignment. In some embodiments, a bottom portion of the device 100 may be substantially convex and a top surface of the dock 1802 may be substantially concave. In other examples, the interfacing surfaces of the dock 1802 and the device 100 may be substantially flat, or may include one or more additional housing features to assist with effecting mutual alignment.

In some embodiments, one or more actuators in the dock 1802 and/or device 100 can be used to align the transmitter and receiver devices. In yet another example, alignment assistance features, such as protrusions and corresponding indentations in the housings of the transmitter and receiver devices, may be used to align the transmitter and receiver devices. The design or configuration of the interface surfaces, one or more alignment assistance mechanisms, and one or more alignment features can be used individually or in various combinations thereof.

Alignment assistance can also be provided with one or more magnetic field sources. For example, a permanent magnet within the dock 1802 may attract a permanent magnet within the device 100. In another example, a permanent magnet within the device 100 may be attracted by a magnetic field produced by the dock 1802. In further examples, multiple alignment assistance features may cooperate to effect alignment of the transmit and receive coils. Power transfer efficiency may also decrease if the power consumption of the electronic device changes (e.g., the electronic device transitions from a trickle charge mode to constant current charge mode) during wireless power transfer.

As discussed previously with respect to FIG. 2, the device 100 may include a processor coupled with or in communication with a memory, one or more communication interfaces, output devices such as displays and speakers, and one or more input devices such as buttons, dials, microphones, or touch-based interfaces. The communication interface(s) can provide electronic communications between the communications device and any external communication network, device or platform, such as, but not limited to, wireless interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. The device 100 may provide information regarding time, health, statuses or externally connected or communicating devices and/or software executing on such devices, messages, video, operating commands, and so forth (and may receive any of the foregoing from an external device), in addition to communications.

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In the example depicted in FIG. 18, the dock 1802 may be connected to an external power source, such as an alternating current power outlet, by power cord 1808. In other embodiments, the dock 1802 may be battery operated. In still further examples, the dock 1802 may include a power cord 1808 in addition to an internal or external battery. Similarly, although the embodiment is shown with the power cord 1808 coupled to the housing of the dock 1802, the power cord 1808 may be connected by any suitable means. For example, the power cord 1808 may be removable and may include a connector that is sized to fit within an aperture or receptacle opened within the housing of the dock 1802.

Although the device 100 is shown in FIG. 18 as larger than the dock 1802, the depicted scale may not be representative of all embodiments. For example, in some embodiments the dock 1802 may be larger than the device 100. In still further embodiments the two may be substantially the same size and shape. In other embodiments, the dock 1802 and device 100 may take separate shapes.

FIG. 19 depicts a simplified block diagram of relevant aspects of the device 100 and dock 1802. It may be appreciated that certain components of both the dock 1802 and device 100 are omitted from the figure for clarity. Likewise, the positions of the elements that are shown are meant to be illustrative rather than necessarily portraying a particular size, shape, scale, position, orientation, or relation to one another, although some embodiments may have elements with one or more of such factors as illustrated.

As described previously with respect to FIG. 2, the device 100 may include one or more electronic components located within the housing 601. For clarity, some of the components and modules described or depicted in various embodiments are omitted from the depiction of FIG. 19. As shown in FIG. 19, the device 100 may include an internal battery 114 that may be used to provide power to the various internal components of the device 100. As described previously, the internal battery 114 may be rechargeable by an external power supply. In the present example, the internal battery 114 is operably connected to a receive coil 1869 via power conditioning circuit 1810.

In the present example, the device 100 includes a receive coil 1869 having one or more windings for inductively coupling with a transmit coil 1832 of the dock 1802. The receive coil 1869 may receive power wirelessly from the dock 1802 and may pass the received power to a battery 114 within the device 100 via power conditioning circuit 1810. The power conditioning circuit 1810 may be configured to convert the alternating current received by the receive coil 1869 into direct current power for use by other components of the device. In one example, the processing units 102 may direct the power, via one or more routing circuits, to perform or coordinate one or more functions of the device 100 typically powered by the battery 114.

As shown in FIG. 19, the dock 1802 includes a transmit coil 1832 having one or more windings. The transmit coil 1832 may transmit power to the device 100 via electromagnetic induction or magnetic resonance. In many embodiments, the transmit coil 1832 may be shielded with a shield element that may be disposed or formed around portions of the transmit coil 1832. Similarly, the receive coil 1869 may also include a shield element that may be disposed or formed around a portion of the receive coil 1869.

As shown in FIG. 19, the dock 1802 also includes a processor 1834 that may be used to control the operation of or coordinate one or more functions of the dock 1802. In some embodiments, the dock 1802 may also include one or more sensors 1836 to determine whether the device 100 is

present and ready to receive transmitted power from the dock 1802. For example, the dock 1802 may include an optical sensor, such as an infrared proximity sensor. When the device 100 is placed on the dock 1802, the infrared proximity sensor may produce a signal that the processor 1834 uses to determine the presence of the device 100. The processor 1834 may, optionally, use another method or structure to verify the presence of the electronic device via sensor 1836. Examples of different sensors that may be suitable to detect or verify the presence of device 100 may include a mass sensor, a mechanical interlock, switch, button or the like, a Hall effect sensor, or other electronic sensor. Continuing the example, after the optical sensor reports that the device 100 may be present, the processor 1834 may activate a communication channel to attempt to communicate with the device 100.

As illustrated in FIG. 19, a bottom surface of the housing of the device 100 may partially contact a top surface of the dock housing. In some implementations, the interfacing surfaces of the device 100 and the dock 1802 may be formed with complementary geometries. For example, as depicted in FIG. 19, the bottom surface of the device 100 is convex and the top surface of the dock 1802 is concave, following the same curvature as the bottom surface of the device 100. In this manner, the complementary geometries may facilitate alignment of the electronic device and dock for efficient wireless power transfer.

In some embodiments, the dock 1802 and device 100 may include other alignment assistance features. For example the device 100 may include an alignment magnet 1838 which is positioned and oriented to attract a corresponding alignment magnet 1840 within the dock 1802. In some cases, when the device 100 is positioned proximate the dock 1802, the alignment magnets 1838, 1840 may be mutually attracted, thereby affecting alignment of the portable electronic device 100 and the dock 1802 along a mutual axis. In other examples, the dock 1802 may include a ferromagnetic material in place of the alignment magnet 1840. In these examples, the alignment magnet 1838 may be attracted to the ferromagnetic material. In still further cases, the receive coil 1869 or transmit coil 1832 may produce a static magnetic field that either attracts or repels either or both of the alignment magnets 1838, 1840.

As shown in FIG. 19, the alignment magnets 1838, 1840 may be positioned within a respective coil 1869, 1832. When the alignment magnets 1838, 1840 are drawn together, the coils 1869, 1832 may be placed into alignment. Additionally, the complementary geometries of the device 100 and the dock 1802 may further facilitate alignment when the alignment magnets 1838, 1840 are drawn together.

7. Example Acoustic Module

As described above, the device may include one or more devices for transmitting and receiving acoustic energy. For the purposes of the following description of the acoustic module, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above. As previously discussed, in some embodiments, the device may include a speaker for transmitting acoustic energy and/or a microphone for receiving acoustic energy. For the purposes of the following description, a speaker device and a microphone are referred to generically as an acoustic module, which may be configured to transmit and/or receive acoustic energy depending on the particular implementation.

FIG. 20 depicts a simplified schematic cross-sectional view of a first embodiment of a device having an acoustic module 2006. The representation depicted in FIG. 20 is not drawn to scale and may omit some elements for clarity. The acoustic module 2006 may represent either a portion of a speaker and/or microphone device described above with respect to the electronic device 100 of FIG. 2.

As shown in FIG. 20, an acoustic port 2020 may be formed in the housing 601 of the electronic device. In the present example, the acoustic port 2020 includes first and second orifices 2031, 2032 that are formed in the housing 601 and acoustically couple the acoustic cavity 2011 of the acoustic module 2006 to the external environment (external to the electronic device). In the present embodiment, the first and second orifices 2031, 2032 are offset with respect to the opening of the acoustic cavity 2011. This configuration may help reduce the direct ingress of liquid 2001 into acoustic cavity 2011 of the acoustic module 2006. Also, as shown in FIG. 20 a shield 2021 or umbrella structure that is formed between the orifices 2031, 2032 blocks the direct ingress of liquid 2001 into the acoustic cavity 2011. As shown in FIG. 20, the acoustic module 2006 also includes a screen element 2015 disposed at one end of the acoustic cavity 2011, which may also prevent the ingress of liquid or other foreign debris into the acoustic cavity 2011. The acoustic module 2006 also includes a seal 2016 disposed between the housing 601 and the connector element 2012 of the module, which may also be configured to prevent the ingress of water into the device and/or module.

In the present example depicted in FIG. 20, the acoustic module 2006 may correspond to the speaker 122 described with respect to some embodiments. As shown in FIG. 20, the acoustic module 2006 includes various components for producing and transmitting sound, including a diaphragm 2010, a voice coil 2009, a center magnet 2008, and side magnets/coils 2007. These components may cooperate to form a speaker acoustic element. In one implementation, the diaphragm 2010 is configured to produce sound waves or an acoustic signal in response to a stimulus signal in the center magnet 2008. For example, a modulated stimulus signal in the center magnet 2008 causes movement of the voice coil 2009, which is coupled to the diaphragm 2010. Movement of the diaphragm 2010 creates the sound waves, which propagate through the acoustic cavity 2011 of acoustic module 2006 and eventually out the acoustic port 2020 to a region external to the device. In some cases, the acoustic cavity 2011 functions as an acoustical resonator having a shape and size that is configured to amplify and/or dampen sound waves produced by movement of the diaphragm 2010.

As shown in FIG. 20, the acoustic module 2006 also includes a yoke 2014, support 2013, connector element 2012, and a cavity wall 2017. These elements provide the physical support of the speaker elements. Additionally, the connector element 2012 and the cavity wall 2017 together form at least part of the acoustic cavity 2011. The specific structural configuration of FIG. 20 is not intended to be limiting. For example, in alternative embodiments, the acoustic cavity may be formed from additional components or may be formed from a single component.

The acoustic module 2006 depicted in FIG. 20 is provided as one example of a type of speaker acoustic module. In other alternative implementations, the acoustic module may include different acoustic elements for producing and transmitting sound, including, for example, a vibrating membrane, piezoelectric transducer, vibrating ribbon, or the like. Additionally, in other alternative implementations, the



acoustic module may be a microphone acoustic module having one or more elements for converting acoustic energy into an electrical impulse. For example, the acoustic module may alternatively include a piezoelectric microphone acoustic element for producing a charge in response to acoustic energy or sound.

As previously mentioned, because the acoustic port 2020 connects the acoustic module 2006 to the external environment, there is a possibility that liquid may accumulate or infiltrate the interior of the module. In some cases, the screen element 2015 or other protective features may not prevent all liquid from entering the acoustic cavity 2011 of the module. For example, if the device is subjected to a liquid under pressure or a directed stream of liquid, some liquid ingress may occur. Additionally, naturally occurring moisture in the air may condense and accumulate over time resulting in the presence of liquid within the module. Thus, in some implementations, the acoustic module 2006 may include one or more elements configured to expel water or liquid that accumulates in, for example, the acoustic cavity 2011 of the module. The liquid expulsion process may include modifying the charge over a portion of the wall of the acoustic cavity 2011 to change the surface energy of the wall and/or producing an acoustic pulse using the diaphragm 2010 to help expel liquid from the acoustic cavity 2011. In some embodiments, the screen 2015 may also have hydrophilic or hydrophobic properties that may facilitate removal of liquid held within the acoustic cavity 2011.

8. Example Antenna and Cover

As previously described, a wearable electronic device may be configured to communicate wirelessly with various external devices and communication networks. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, as previously discussed with respect to FIG. 2, the device may include one or more communication channels that are configured to transmit and receive data and/or signals over a wireless communications network or interface. Example wireless interfaces include radio frequency cellular interfaces, Bluetooth interfaces, Wi-Fi interfaces, or any other known communication interface.

In some implementations an antenna may be disposed with respect to the cover (e.g., crystal) of a device to facilitate wireless communications with an external device or communication network. In some cases, it may be advantageous to integrate an antenna into the cover to improve the transmission and reception of wireless signals from the device. In particular, the cover of the device may have dielectric properties that facilitate the transmission of radio frequency signals while also protecting the antenna from physical damage or interference. Additionally, if the antenna is integrated into a perimeter portion of the cover, the visual appearance or clarity of the cover may be minimized. Furthermore, the embodiments described below with respect to FIGS. 21A-B may be used to integrate an antenna external to the housing, without increasing the thickness of the device body.

FIG. 21A depicts a perspective exploded view of a cover 2100 and an antenna assembly 2130. The cover 2100 depicted in FIG. 21A is viewed from an inner surface 2124 that is configured to attach to or interface with the opening of the housing (described above with respect to FIG. 1). As

shown in FIG. 21A, a groove 2128 may be formed within the inner surface 2124. In this example, the groove 2128 is formed around the periphery of the cover 2100. As mentioned previously, this may be advantageous in minimizing the visual impact of having the antenna assembly 2130 located within the cover 2100.

As shown in FIG. 21A the antenna assembly 2130 includes an antenna ring 2134 and a terminal 2140 which may interface with an electrical connector 2150. In the present embodiment, the groove 2128 formed in the surface of the cover 2100 may be configured to accept the antenna ring 2134. In particular, the groove 2128 may receive the entire antenna ring 2134 without a portion of the antenna ring 2134 protruding past the inner surface 2124, when the antenna ring 2134 is installed. In some cases, the groove 2128 is formed to be a clearance or near clearance fit with the diameter of the antenna ring 2134. Thus, in some cases, the antenna ring 2134 may substantially fill the groove 2128 when the ring is installed. In some cases, the groove 2128 may be configured to retain the antenna ring 2134 due to a slight interference fit or due to a feature formed within either the cover 2100 and/or the antenna assembly 2130. In the present embodiment, the antenna assembly 2130 may be installed in the cover 2100 and then connected to other electronics via the terminal 2140 and the connector 2150, which may protrude into an opening in the case or housing.

FIG. 21B depicts a cross-sectional view of the cover and antenna at the connection point. In particular, FIG. 21B depicts a detail cross-sectional view of the cover 2100 installed within the housing 601 at a region near the terminal 2140. In this example, the cover 2100 is attached to a shelf of the housing 601 via a compressible element 2122. The compressible element 2122 may provide a seal against water or other contaminants and also provide compliance between the cover 2100 and the housing 601. The compressible element 2122 may be formed from a nitrile or silicone rubber and may also include an adhesive or other bonding agent.

As shown in FIG. 21B, the antenna ring 2134 is disposed entirely within the groove 2128. In this case, the antenna ring 2134 does not protrude past the inner surface 2124. The antenna ring 2134 is electrically connected to the terminal 2140, which protrudes into an opening in the housing 601. As shown in FIG. 21B, the terminal 2140 includes conductive pads 2142 for electrically connecting to the antenna ring 2134. In this example, spring clips 2152 are configured to mechanically and electrically connect to the conductive pads 2142 on the terminal 2140. One advantage to the configuration depicted in FIG. 21B is that the antenna assembly 2130 may be installed in the cover 2100 before the cover 2100 is installed in the housing 601. The terminal 2140 and connector 2150 facilitate a blind connection that may assist electrical connection as the cover 2100 is installed. Additionally, the configuration depicted in FIG. 21B may allow for some movement between the cover 2100 and the housing 601 without disturbing the electrical connection with the antenna ring 2134.

9. Example Haptic Module

As described above, the device may include one or more haptic modules for providing haptic feedback to the user. The embodiments described herein may relate to or take the form of durable and thin haptic feedback elements suitable to provide a perceivable single pulse haptic feedback. In general, a haptic device may be configured to produce a mechanical movement or vibration that may be transmitted through the housing and/or other component of the device. In some cases, the movement or vibration may be transmit-

ted to the skin of the user and perceived as a stimulus or haptic feedback by the user. In some implementations, the haptic feedback may be coupled to one or more device outputs to alert the user of an event or activity. For example, a haptic output may be produced in combination with an audio output produced by the speaker, and/or a visual output produced using the display.

The space constraints associated with a small wrist-worn device may present unique challenges to integrating a haptic mechanism into wearable electronics. In particular, a haptic mechanism may use a moving mass used to create the movement or vibration of the haptic output. The larger the mass that is moved, the easier it may be to create a perceivable stimulus using the haptic mechanism. However, a large moving mass and the supporting mechanism may be difficult to integrate into the compact space of, for example, the housing of a wearable electronic wristwatch.

Thus, the haptic module implemented in some embodiments may be configured to maximize the mechanical energy that is produced in a very compact form factor. FIGS. 22A-B depict one example haptic mechanism that may be particularly well suited for use in a wearable electronic device. While the embodiment described with respect to FIGS. 22A-B is provided as one example, the haptic module is not limited to this particular configuration.

FIG. 22A depicts a three-quarters perspective view of a haptic device 112, with a top, front and left sidewall of the housing 2220 removed to expose internal components. FIG. 22B depicts a cross-sectional perspective view of the haptic device 112 cut in half to expose the internal components. In this example, a coil 2200 is used to induce movement of a frame 2260, which houses a central magnet array 2210. As shown in FIGS. 22A-B, the movement of the frame 2260 is guided by a shaft 2250 that is fixed with respect to a housing 2220.

In the present example, the coil 2200 may be energized by transmitting a current (e.g., from the battery) along a length of a wire that forms the coil 2200. A direction of the current along the wire of the coil 2200 determines a direction of a magnetic field that emanates from the coil 2200. In turn, the direction of the magnetic field determines a direction of movement of the frame 2260 housing the central magnet array 2210. One or more springs may bias the frame 2260 towards the middle region of the travel. In this example, the frame 2260 and central magnet array 2210, through operation of the coil 2200, function as a moving mass, which generates a tap or vibration. The output of the haptic device 112, created by the moving mass of the frame 2260 and central magnet array 2210, may be perceived as a haptic feedback or stimulus to the user wearing the device.

For example, when the coil 2200 is energized, the coil 2200 may generate a magnetic field. The opposing polarities of the magnets in the magnet array 2210 generates a radial magnetic field that interacts with the magnetic field of the coil 2200. The Lorentz force resulting from the interaction of the magnetic fields causes the frame 2260 to move along the shaft 2250 in a first direction. Reversing current flow through the coil 2200 reverses the Lorentz force. As a result, the magnetic field or force on the central magnet array 2210 is also reversed and the frame 2260 may move in a second direction. Thus, frame 2260 may move in both directions along the shaft 2250, depending on the direction of current flow through the coil 2200.

As shown in FIG. 22A, the coil 2200 encircles the central magnet array 2210, which is disposed near the center of the frame 2260. As previously described, the coil 2200 may be energized by transmitting a current along the length of the

wire forming the coil 2200, and the direction of the current flow determines the direction of the magnetic flux emanating from the coil 2200 in response to the current. Passing an alternating current through the coil 2200 may cause the central magnet array 2210 (and frame 2260) to move back and forth along a shaft 2250. In order to prevent the central magnet array 2210 from being attracted to the shaft 2250, which could increase friction between the two and thereby increase the force necessary to move the central magnet array 2210 and frame 2260, the shaft 2250 may be formed from a non-ferrous material such as tungsten, titanium, stainless steel, or the like.

As depicted in FIGS. 22A-B, the coil 2200 is positioned within a frame 2260 that holds the central magnet array 2210, but is not affixed to the coil 2200. Rather, an air gap separates the coil 2200 from the central magnet array 2210 and the frame 2260 is free to move with respect to the coil 2200, which is generally stationary. Further, the frame 2260 generally moves with the central magnet array 2210. As illustrated in FIGS. 22A-B, the frame 2260 may have an aperture formed therein of sufficient size to contain the coil 2200. Even when the frame and central magnet array are maximally displaced within the housing 2220 (e.g., to one end or the other of the shaft 2250), the coil 2200 does not contact any portion of the frame 2260. It should be appreciated that the coil 2200 remains stationary in the housing 2220 while the frame 2260 and central magnet array 2210 move, although in other embodiments the coil 2200 may move instead of, or in addition to, the frame and/or central magnet array. However, by keeping the coil 2200 stationary, it may be easier to provide interconnections for the coil, such as between the coil and the flex, and therefore reduce the complexity of manufacture.

As shown in FIGS. 22A-B, the central magnet array 2210 may be formed from at least two magnets 2211, 2212 of opposing polarities. A center interface 2270 may be formed from a ferrous or non-ferrous material, depending on the embodiment. A ferrous material for the center interface 2270 may enhance the overall magnetic field generated by the central magnet array 2210, while a non-ferrous material may provide at least a portion of a return path for magnetic flux and thus assist in localizing the flux within the housing 2220. In some embodiments, the magnets 2211, 2212 are formed from neodymium while the frame is tungsten. This combination may provide a strong magnetic field and a dense mass, thereby yielding a high weight per volume structure that may be used as the moving part of the haptic device 112.

10. Example Crown Module

As described above, the device may include a crown that may be used to accept user input to the device. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a crown may be used to accept rotary input from the user, which may be used to control aspects of the device. The crown may be knurled or otherwise textured to improve grip with the user's finger and/or thumb. In some embodiments, a crown may be turned by the user to scroll a display or select from a range of values. In other embodiments, the crown may be rotated to move a cursor or other type of selection mechanism from a first displayed location to a second displayed location in order to select an icon or move the selection mechanism between various icons that are output on the display. In a time



keeping application, the crown may also be used to adjust the position of watch hands or index digits displayed on the display of the device. The crown may also be used to control the volume of a speaker, the brightness of the display screen, or control other hardware settings.

In some embodiments, the crown may also be configured to accept linear, as well as rotary, input. For example, the crown may be configured to translate along an axis when pressed or pulled by the user. In some cases, the linear actuation may be used as additional user input. The actuation may provide a binary output (actuated/not actuated) or may also provide a non-binary output that corresponds to the amount of translation along the axis of motion. In some instances, the linear input to the crown may be combined with the rotary input to control an aspect of the device.

The embodiments described herein may be used for at least a portion of the crown module integrated into a wearable electronic device. The embodiments are provided as examples and may not include all of the components or elements used in a particular implementation. Additionally, the crown module is not intended to be limited to the specific examples described below and may vary in some aspects depending on the implementation.

In some embodiments, an optical encoder may be used to detect the rotational motion of the crown. More specifically, the example provided below with respect to FIG. 23 may use an optical encoder to detect rotational movement, rotational direction and/or rotational speed of a component of the electronic device. Once the rotational movement, rotational direction and/or rotational speed have been determined, this information may be used to output or change information and images that are presented on a display or user interface of the electronic device.

Integrating an optical encoder into the space constraints of a typical wearable electronic device may be particularly challenging. Specifically, some traditional encoder configurations may be too large or delicate for use in a portable electronic device. The optical encoder described below may provide certain advantages over some traditional encoder configurations and may be particularly well suited for use with a crown module of a wearable electronic device.

As shown in the example embodiment of FIG. 23, the optical encoder of the present disclosure includes a light source 2370, a photodiode array 2380, and a shaft 2360. However, unlike typical optical encoders, the optical encoder of the present disclosure utilizes an encoding pattern disposed directly on the shaft 2360. For example, the encoding pattern includes a number of light and dark markings or stripes that are axially disposed along the shaft 2360. Each stripe or combination of stripes on the shaft 2360 may be used to identify a position of the shaft 2360. For example, as light is emitted from the light source 2370 and reflected off of the shaft 2360 into the photodiode array 2380, a position, rotation, rotation direction and rotation speed of the shaft 2360 may be determined. Once the rotation direction and speed are determined, this information may be used to output or change information or images that are presented on the display or user interface of the electronic device.

In other embodiments, the shape or form of the shaft of the encoder may be used to determine a position, rotation, rotation direction and rotation speed of the shaft. For example, the shaft may be fluted or have a number of channels that cause the light to be reflected in a number of different directions. Accordingly, a diffractive pattern may be used to determine the rotation, rotation direction and rotation speed of the shaft.

FIG. 23 illustrates a simplified depiction of the device 100 and crown module 642 in accordance with some embodiments. As shown in FIG. 23, the crown module 642 may be integrated with the housing 601 of the device 100 and may be formed from a dial 2340 disposed at the end of a shaft 2360. In the present embodiment, the crown module 642 also forms part of the optical encoder. As discussed above, the crown module 642 includes an optical encoder that includes a shaft 2360, a light source 2370, and a photodiode array 2380. Although a photodiode array is specifically mentioned, embodiments disclosed herein may use various types of sensors that are arranged in various configurations for detecting the movement described herein. For example, the movement of the shaft 2360 may be detected by an image sensor, a light sensor such as a CMOS light sensor or imager, a photovoltaic cell or system, photo resistive component, a laser scanner and the like.

The optical encoder may produce an encoder output that is used to determine positional data of the crown module 642. In particular, the optical encoder may produce an output that is used to detect that movement of the dial 2340 including the direction of the movement, speed of the movement and so on. The movement may be rotational movement, translational movement, angular movement, and so on. The optical encoder may also be used to detect the degree of the change of rotation of the dial 2340 and/or the angle of rotation of the dial 2340 as well as the speed and the direction of the rotation of the dial 2340.

The signals or output of the optical encoder may be used to control various aspects of other components or modules of the device. For example, continuing with the time keeping application example discussed above, the dial 2340 may be rotated in a clockwise manner in order to advance the displayed time forward. In one implementation, the optical encoder may be used to detect the rotational movement of the dial 2340, the direction of the movement, and the speed at which the dial 2340 is being rotated. Using the output from the optical encoder, the displayed hands of a time keeping application may rotate or otherwise move in accordance with the user-provided rotational input.

Referring back to FIG. 23, the crown module 642 may be formed from dial 2340 that is coupled to the shaft 2360. In some cases, the shaft 2360 and dial 2340 may be formed as a single piece. As the shaft 2360 is coupled to, or is otherwise a part of the dial 2340, as the dial 2340 rotates or moves in a particular direction and at a particular speed, the shaft 2360 also rotates or moves in the same direction and with the same speed.

As shown in FIG. 23, the shaft 2360 of the optical encoder includes an encoding pattern 2365. As discussed above, the encoding pattern 2365 may be used to determine positional information about the shaft 2360 including rotational movement, angular displacement and movement speed. As shown in FIG. 23, the encoding pattern 2365 may include a plurality of light and dark stripes.

Although light stripes and dark stripes are specifically mentioned and shown, the encoding pattern 2365 may consist of various types of stripes having various shades or colors that provide surface contrasts. For example, the encoding pattern 2365 may include a stripe or marking that has a high reflective surface and another stripe that has a low reflective surface regardless of the color or shading of the stripes or markings. In another embodiment, a first stripe of the encoding pattern 2365 may cause specular reflection while a second stripe of the encoding pattern 2365 may cause diffuse reflection. When the reflected light is received by the photodiode array 2380, a determination may be made

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as to the position and movement of the shaft such as described below. In embodiments where a holographic or diffractive pattern is used, the light from the light source 2370 may diffract from the shaft 2360. Based on the diffracted light, the photodiode array 2380 may determine the position, movement and direction of movement of the shaft 2360.

In some embodiments, the stripes of the encoding pattern 2365 extend axially along the shaft 2360. The stripes may extend along the entire length of the shaft 2360 or partially along a length of the shaft 2360. In addition, the encoding pattern 2365 may also be disposed around the entire circumference of the shaft 2360. In other embodiments, the encoding pattern 2365 may include a radial component. In yet other embodiments, the encoding pattern 2365 may have both a radial component and an axial component.

In some embodiments, the crown module may also include a tactile switch for accepting translational input from the user. FIGS. 24A-B depict another example of a crown module 642a having a tactile switch assembly 2410. As shown in FIG. 24A, the tactile switch assembly 2410 may include a dial 2448 (or button), a coupling 2418, a shear plate 2456, and a tactile switch 2414.

In the embodiment depicted in FIGS. 24A-B, the dial 2448 is translatable and/or rotatable relative to the housing. The ability of the dial 2448 to translate and rotate relative to the housing allows a user to provide a rotational force and/or translating force to the tactile switch assembly. In particular, the dial 2448 of the present example may be operably coupled to or form part of an optical encoder, in accordance with the example described above with respect to FIG. 23.

In the present example, the dial 2448 includes an outer surface 2432 that is configured to receive a rotary or rotational user input and a stem 2450 that extends from an interior surface 2434 of the dial 2448. The stem 2450 may define a coupling aperture that extends longitudinally along a length or a portion of a length of the stem 2450. In the depicted example, the stem 2450 may be hollow or partially hollow.

In the example depicted in FIGS. 24A-B, the coupling 2418 may be a linkage, such as a shaft, that couples the dial 2448 to the tactile switch 2414. The coupling 2418 may be integrally formed with the dial 2448 or may be a separate component operably connected thereto. For example, the stem 2450 of the dial 2448 may form the coupling member that is integrally formed with the dial 2448. The coupling 2418 may be made of a conductive material, such as one or more metals or metal alloys. Due to the conductive characteristics, the coupling 2418 may further act to electrically couple the dial 2448 to the tactile switch 2414 and shear plate 2456. In the example depicted in FIGS. 24A-B, the shear plate 2456 is positioned between the coupling 2418 and the tactile switch 2414. In some embodiments, the shear plate 2456 may prevent or reduce shearing forces from the coupling from being transmitted to the tactile switch. The shear plate 2456 also allows transfer of linear force input from the dial 2448 to the switch 2414.

The configuration depicted in FIGS. 24A-B may be used to accept both rotational and translational input from the user. For example, if a user provides a rotational force to the dial 2448, the coupling 2418 and dial 2448 may rotate in the direction of the force. The coupling 2418 may be attached to or integrated with one or more sensors that are configured to detect rotational movement. For example the coupling 2418 may be integrated with an optical encoder, similar to the example described above with respect to FIG. 23. Additionally, if a user provides a translational force to the dial 2448,

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the force may be transmitted through the dial 2448 and coupling 2418 to actuate the switch 2414. In some cases, the switch 2414 includes a metal dome switch that is configured to provide a tactile feedback when actuated. In some cases, the actuation of a dome switch may be perceived by the user as a click or release as the switch 2414 is actuated. Once the force has been removed from the dial 2448, the dome switch resiliently returns to its original position, providing a biasing force against the coupling 2418 to return both the dial 2448 and the coupling 2418 to their original positions. In some embodiments, the tactile switch 2414 may include a separate biasing element, such as a spring, that exerts a force (either directly or indirectly via the shear plate) against the coupling. FIG. 24A depicts the tactile switch assembly 2410 when there is no force applied (un-actuated). FIG. 24B depicts the tactile switch assembly 2410 when there is a translational force applied to the dial 2448 (actuated).

#### 11. Example Band Attachment Mechanism

For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

As described above, a wearable electronic device may include a band that is attached to a device body having one or more receiving features. In particular, the housing may include or form a receiving feature that facilitates an interchange or replacement of different bands that are used to secure the device to the wrist of the user. By replacing or interchanging bands the device may be adapted for multiple uses ranging from sporting activities to professional or social activities.

In some embodiments, the receiving features are configured to be operated without the use of special tools or fixtures. For example, the bands may be interchanged by hand or with the help of a simple tool, such as a pointed object. Additionally or alternatively, a tool or other component, such as a component of the device to which the attachment system is coupled, may be configured to actuate a button or other component of the attachment system to secure and/or release the band from the device. In one embodiment, the lug portion of a band may be configured to be inserted into an opening or channel portion of the receiving feature. Once the lug of the band has been inserted into the opening, the lug may slide within the opening of the device until the band is secured or otherwise coupled to the device. The coupling between the band and the receiving feature may provide a secure attachment of the band to the housing or device body. Just as the band is configured to slide into the channel of the receiving feature, the lug may also slide out of the channel of the receiving feature allowing the band to be detached from the device body.

In one embodiment, the receiving feature includes a locking mechanism, which may be integrated with portions of either the band or the receiving feature. In one example, as the band is inserted into a receiving feature of the device, the locking mechanism interfaces with a portion of the receiving feature to lock or otherwise secure the band within the receiving feature. The locking mechanism may also be configured to interface with a releasing mechanism associated with the receiving feature. For example, a releasing mechanism may be configured to disengage or release the locking mechanism. In some implementations, actuation of the releasing mechanism causes the locking mechanism to be released and allows the band to be removed by sliding within the receiving feature.



FIG. 25A depicts a receiving feature and band assembly as viewed from the bottom of the device body. As shown in FIG. 25A, a receiving feature 623a includes an opening or channel 2501 that is formed into the body or housing of the device. The channel 2501 is configured to receive the lug 2510 attached to an end of the band strap 621a. The receiving feature 623a may also include a locking mechanism 2530 that is configured to maintain the band strap 621a within the channel 2501 once it has been installed. As discussed above, the locking mechanism 2530 may be releasable by the user, which may facilitate band replacement. In this example, the locking mechanism 2530 includes a spring-loaded retaining mechanism that engages the lug 2510 to retain the lug 2510 in the channel 2501 and maintain the attachment of the band strap 621a to the device. As shown in FIG. 25A, the locking mechanism 2530 also includes a button located on the bottom of the housing that may be depressed by the user to release the locking mechanism and allow the lug 2510 and the band strap 621a to be removed from the channel 2501. In the present example, the button of the locking mechanism 2530 is located on a curved portion of the case or housing. In some embodiments, the button of the locking mechanism 2530 is located along the centerline of the case or housing.

In some embodiments, the opening or channel 2501 of the receiving feature 623a includes a port or connector for receiving a mating electrical component. In some embodiments, the connector or port is covered by a label or sticker so that the inside surface of the opening or channel 2501 appears continuous. The connector or port may be located along the vertical centerline of the case or housing.

FIG. 25B depicts an example exploded view of the receiving feature 623a and the lug 2510 of the band strap 621a. As shown in FIG. 25B, the band strap 621a may be formed from a separate part and attached to lug 2510 via a pivot or other type of joint. In other embodiments, the band strap 621a may have an end feature that is integrally formed as part of the band strap 621a. As also shown in FIG. 25B, the lug 2510 may be attached to the receiving feature 623a by aligning the axis of the lug 2510 with the axis of the channel 2501 and then sliding the lug 2510 into the channel 2501.

FIG. 25C depicts an example assembly sequence of the lug 2510 being inserted into the channel 2501 of the receiving feature 623a. As shown in FIG. 25C, the lug 2510 may be positioned along the side of the receiving feature 623a having the lug 2510 approximately aligned with the channel 2501 of the receiving feature 623a. The lug 2510 (and band strap 621a) may then be inserted into the channel 2501 of the receiving feature 623a by sliding the lug 2510 along the length of the channel 2501. Once the lug 2510 is approximately centered in the channel 2501 of the receiving feature 623a, the locking mechanism 2530 or other securing feature may engage, thereby retaining the lug 2510 (and band strap 621a) within the channel 2501. As previously discussed, the lug 2510 (and band strap 621a) may be removed from the receiving feature 623a by depressing the button of the locking mechanism 2530, which may disengage the lock and allow movement of the lug 2510 within the channel 2501.

The example described above is provided with respect to one example embodiment. The geometry of the end of the band strap and/or the geometry of the channel may vary depending on the implementation. Additionally, the engagement mechanism may vary depending on the design of the band strap and the device body. The geometry or layout of the features may vary and remain within the scope of the present disclosure. Additionally, while the examples pro-

vided above are described with respect to attaching a band strap to a device body, the receiving feature (623a) may be used to attach a variety of other parts to the device body. For example a lanyard, cable, or other accessory may be attached to the device body using the receiving feature and other similar features.

#### 12. Example Bands

As described above, a wearable electronic device may include a band that is used to secure the device to the wrist of a user. In some embodiments, the band may be formed from two band straps that are attached to the housing of the device body. The band straps may be secured around the wrist of a user by a clasp or latching mechanism. As also described above, the device may be configured to facilitate replacement of the band. This feature may allow the use of a variety of types of bands, which may adapt the device for multiple uses ranging from sporting activities to professional or social activities.

In some cases, the band may be formed from a woven textile material. In one example, the band is formed from a woven material that includes one or more strands or threads formed from a natural or synthetic material. The woven material may be formed, for example, from a plurality of warp threads that are woven around one or more weft threads. More specifically, the woven material may include a plurality of warp threads disposed along the length of the band, and at least one weft thread positioned perpendicular to, and coupled to, woven or interlaced between the plurality of warp threads. In some cases, the plurality of warp threads may run the entire length of the woven portion of the band strap. Additionally, in some cases, the at least one weft thread may include a single thread that may be continuously woven between the plurality of warp threads or, alternatively, may include a plurality of threads that may be woven between the plurality of warp threads. A weft thread that is woven between a plurality of warp threads may form consecutive cross-layers with respect to the plurality warp threads in order to form the band.

In some cases, one or more of the strands or threads may be a metallic or conductive material. This may improve the strength of the band and may also facilitate coupling with magnetic elements, such as a metallic clasp. In some cases, other elements may be woven into the band, including, for example, product identifying elements, decorative elements, or functional components.

In other embodiments, the band may be formed from a metallic mesh material. In one example, the metallic mesh is formed from an array of links that are interlocked to form a sheet of fabric. Some or all of the links in the mesh may be formed from a ferromagnetic material, which may facilitate magnetic engagement with a magnetic clasp. In some cases, each link of the mesh is formed from a section of metallic filament that is bent or formed into a closed shape. Each closed shape may be interlocked with one or more adjacent links to form a portion of the sheet or fabric. In some cases, a metallic filament is formed around a series of rods or pins that are disposed at a regular spacing within the mesh. In some cases, one or more strands or filaments that may be formed from a ferromagnetic material are woven or integrated with the links of the mesh.

In other examples, the band may be formed from a sheet of material. For example, the band may be formed from a synthetic leather, leather, or other animal hide. Additionally or alternatively, the band may be formed from a polymer material, an elastomer material, or other type of plastic or synthetic. In some cases, the band is formed from a silicone sheet material.

The clasp that is used to attach the free ends of the band straps may vary depending on the material that is used and the construction of the band. For example, as mentioned above, a metallic mesh material may use a metallic clasp to join the ends of the band. Additionally, a leather band may be integrated with magnetic and/or ferromagnetic components and may include a magnetic clasp. In some embodiments, the free ends of the band straps are secured using a buckle or tang on a first band strap that is configured to interface with a hole or aperture in a second band strap. A variety of other clasp configurations may also be used.

13. Example Display

For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above. As described above, the device includes a display disposed within the housing or enclosure. The device may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user, including, for example, a graphical user interface, notifications, health statistics, and the like. In some cases, the display may be configured to present the current time and date similar to a traditional watch or timepiece.

In some embodiments, the display is formed from an organic light emitting diode (OLED) display element. An active region of the display may include an array of light-emitting display pixels 2604 such as array 2602, shown in FIG. 26. Pixels 2604 may be arranged in rows and columns in array 2602 and may be controlled using a pattern of control lines. Each pixel may include a light-emitting element such as organic light-emitting diode 2612 and associated control circuitry 2610. Control circuitry 2610 may be coupled to the data lines 2606 and gate lines 2608 so that control signals may be received from driver circuitry, which may be implemented as an integrated circuit. Although described as an OLED display, certain embodiments may implement other display technology, such as LCD displays and the like.

To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device 100, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device 100 may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

Although the disclosure above is described in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments but instead defined by the claims herein presented.

I claim:

1. An electronic device, comprising:
  - a housing defining a first opening opposite to a second opening;
  - a band attached to the housing and configured to secure the electronic device to a user;
  - a display positioned in the first opening;
  - a ceramic cover disposed over the second opening and forming a portion of an exterior surface of the electronic device;
  - a biosensor module disposed within the second opening below the ceramic cover; and
  - a wireless charging receive coil aligned with the second opening and below the ceramic cover;wherein:
  - the ceramic cover is configured to pass optical signals generated by the biosensor module; and
  - the ceramic cover is configured to pass wireless power from an external wireless charging device to the wireless charging receive coil.
2. The electronic device of claim 1, wherein the biosensor module comprises:
  - a light source configured to emit light toward a region of skin of the user; and
  - a detector configured to receive light reflected from the region of skin.
3. The electronic device of claim 2, wherein:
  - the ceramic cover defines a first opening to transmit the light from the light source; and
  - the ceramic cover defines a second opening to receive the light reflected from the region of skin.
4. The electronic device of claim 2, wherein:
  - the light source and the detector are configured to measure changes in light absorption by the region of skin;
  - the electronic device is configured to compute a health metric using the measured change in light absorption; and
  - the display is configured to display information associated with the health metric.
5. The electronic device of claim 2, wherein the light source and the detectors are configured to operate as a photoplethysmogram (PPG) sensor.
6. The electronic device of claim 1, wherein:
  - the ceramic cover is a disk having a disk diameter that is greater than an opening diameter of the second opening; and
  - the ceramic cover forms a water-tight seal with the housing along a perimeter of the ceramic cover.
7. The electronic device of claim 1, wherein:
  - the second opening has an opening diameter;
  - the wireless charging receive coil has a coil diameter that is less than the opening diameter; and
  - the wireless charging receive coil is configured to receive the wireless power through the second opening.
8. The electronic device of claim 1, wherein:
  - the ceramic cover has a convex contoured shape that protrudes toward the user; and
  - the convex contoured shape facilitates alignment between the ceramic cover and a mating surface of the external wireless charging device.
9. A wearable electronic device, comprising:
  - a housing comprising a bottom portion defining an opening;
  - a biosensor module aligned with the opening;
  - a wireless charging receive coil positioned within the housing and aligned with the opening;

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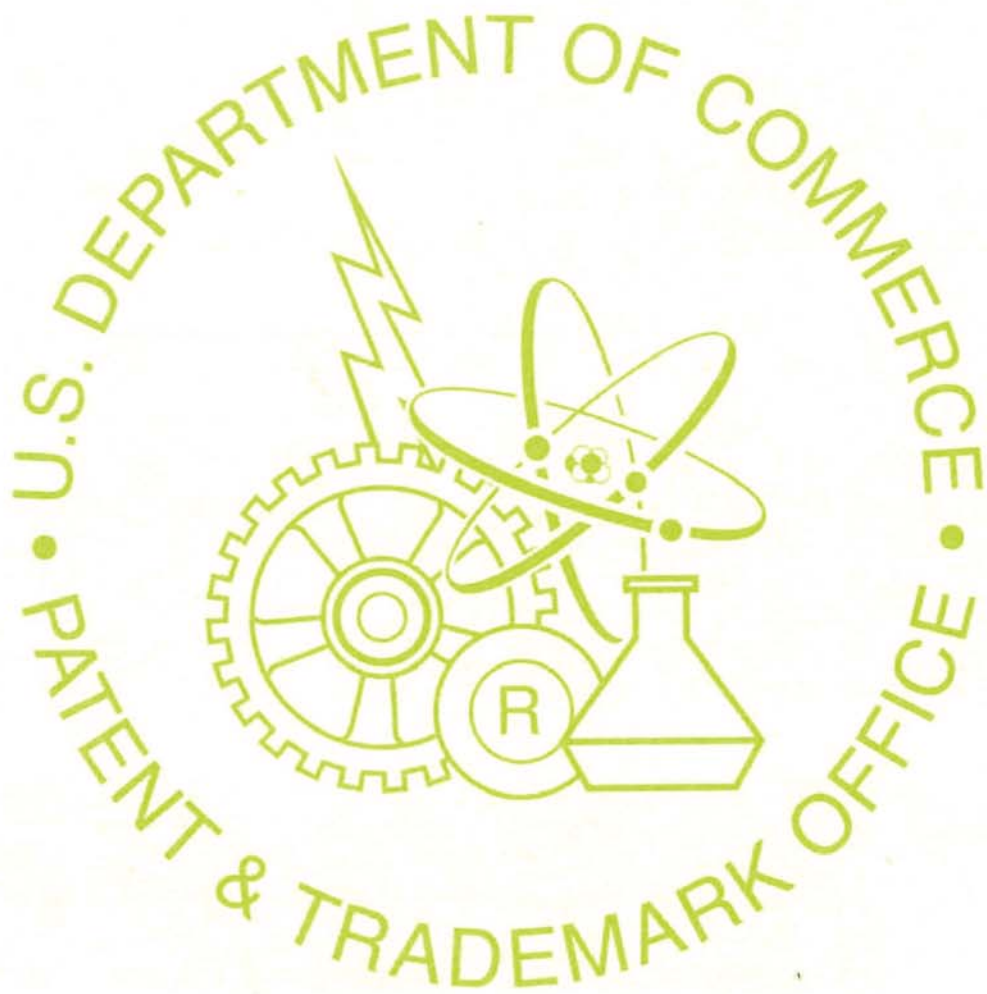
a battery operably coupled to the wireless charging receive coil; and  
a cover disposed over the biosensor module; wherein:  
the cover is configured to pass optical signals to and from the biosensor module; and  
the cover is configured to pass wireless power to the wireless charging receive coil.  
10. The wearable electronic device of claim 9, wherein: the housing is formed from a metal material; and the cover is formed from a non-metal material.  
11. The wearable electronic device of claim 9, wherein: the wireless charging receive coil has a coil diameter that is less than a diameter of the biosensor module; and the wireless charging receive coil is configured to receive the wireless power through the biosensor module.  
12. The wearable electronic device of claim 9, wherein: the cover is a disk having a convex shape that protrudes away from the housing; and the convex shape is configured to facilitate alignment with a concave surface of an external inductive power transmitter dock.  
13. The wearable electronic device of claim 12, wherein: the wearable electronic device is magnetically coupled to the external inductive power transmitter dock through the cover and the biosensor module.  
14. The wearable electronic device of claim 9, wherein: the biosensor module includes an array of optical components; and the cover includes an array of windows, each window aligned with a corresponding optical component of the array of optical components.  
15. An electronic watch, comprising:  
a housing defining an interior cavity and a bottom portion having an opening;  
a band attached to the housing and configured to secure the electronic watch to a user;

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a biosensor module positioned along the bottom portion of the housing and configured to transmit optical signals and receive reflected optical signals through the opening of the housing; and  
a wireless charging receive coil positioned within the interior cavity and configured to receive wireless power through the opening of the housing.  
16. The electronic watch of claim 15, wherein: the wireless charging receive coil is configured to receive power from an external inductive power transmitter dock; and the electronic watch is configured to magnetically couple with the external inductive power transmitter dock.  
17. The electronic watch of claim 15, wherein: the wireless charging receive coil is configured to receive power from an external inductive power transmitter dock; the electronic watch defines a convex contoured surface along the bottom portion; and the convex contoured surface is configured to facilitate alignment with a concave contoured surface of the external inductive power transmitter dock.  
18. The electronic watch of claim 17, wherein the convex contoured surface is configured to protrude toward a portion of skin of the user when the electronic watch is worn.  
19. The electronic watch of claim 15, wherein: the electronic watch is configured to compute a health metric using the biosensor module; and the health metric is one or more of: a heart rate, a respiration rate, a blood oxygenation level, a blood volume estimate, or blood pressure.  
20. The electronic watch of claim 19, wherein: the electronic watch includes a display; and the display is configured to display information associated with the health metric.

\* \* \* \* \*

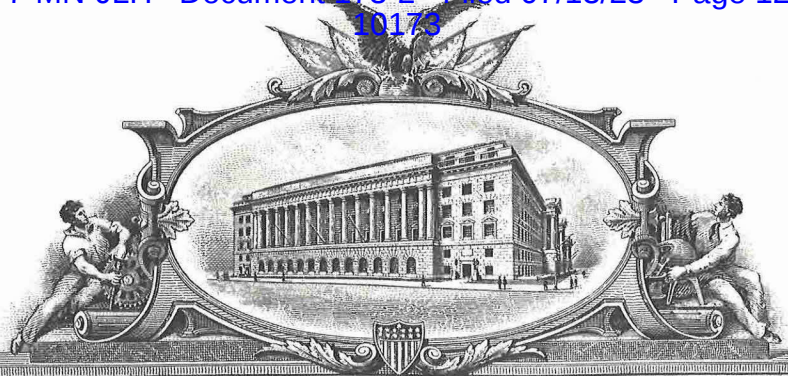






# **EXHIBIT 7**

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# THE UNITED STATES OF AMERICA

**TO ALL TO WHOM THESE PRESENTS SHALL COME:**

UNITED STATES DEPARTMENT OF COMMERCE  
United States Patent and Trademark Office

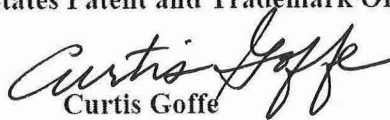
February 2, 2023

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(12) **United States Patent**  
**Rothkopf et al.**

(10) **Patent No.:** **US 10,942,491 B2**  
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(54) **WEARABLE ELECTRONIC DEVICE**

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**Related U.S. Application Data**

(63) Continuation of application No. 15/261,917, filed on Sep. 10, 2016, now Pat. No. 10,627,783, and a (Continued)

(57) **ABSTRACT**

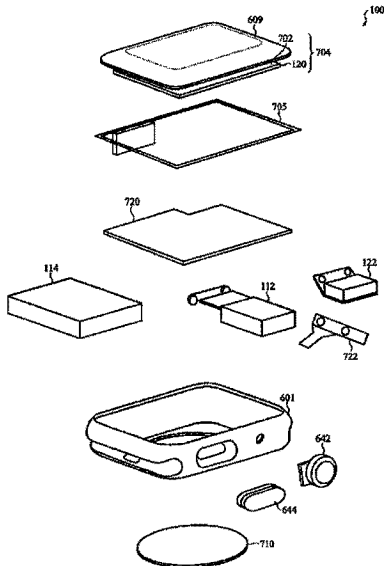
A consumer product that is a portable and, in some cases, a wearable electronic device. The wearable electronic device may have functionalities including: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating with other electronic devices or services; visually depicting data on a display; gather data from one or more sensors that may be used to initiate, control, or modify operations of the device; determine a location of a touch on a surface of the device and/or an amount of force exerted on the device, and use either or both as input.

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(58) **Field of Classification Search**  
None  
See application file for complete search history.

**19 Claims, 26 Drawing Sheets**



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continuation of application No. 15/261,912, filed on Sep. 10, 2016, now Pat. No. 10,620,591, and a continuation of application No. 15/261,914, filed on Sep. 10, 2016, now Pat. No. 10,613,485, and a continuation of application No. 14/842,617, filed on Sep. 1, 2015, now Pat. No. 10,599,101.

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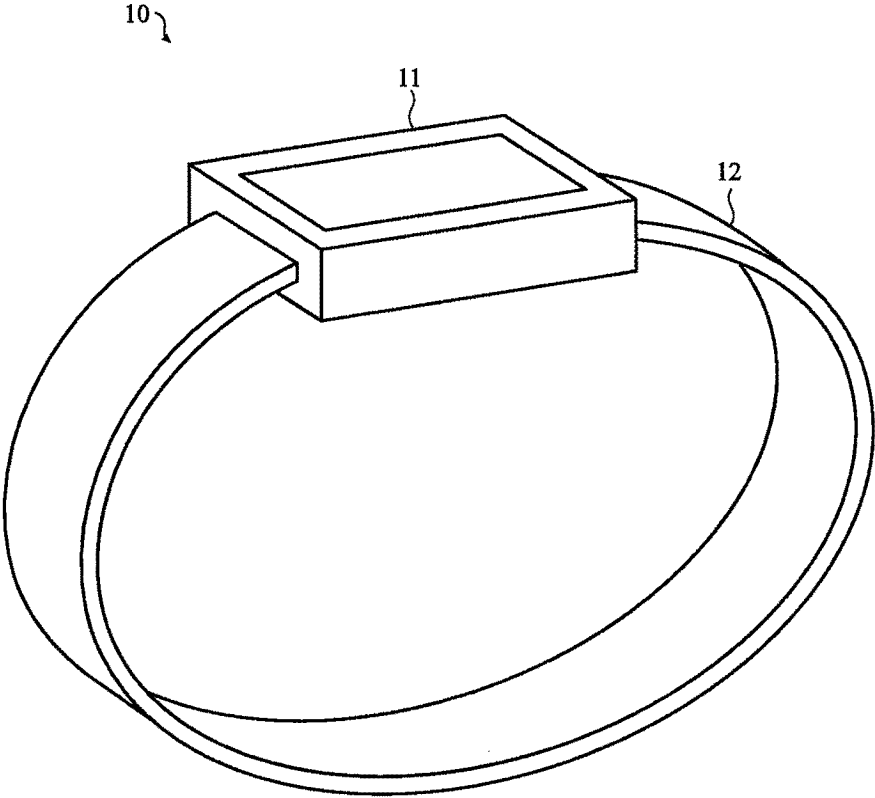


FIG. 1

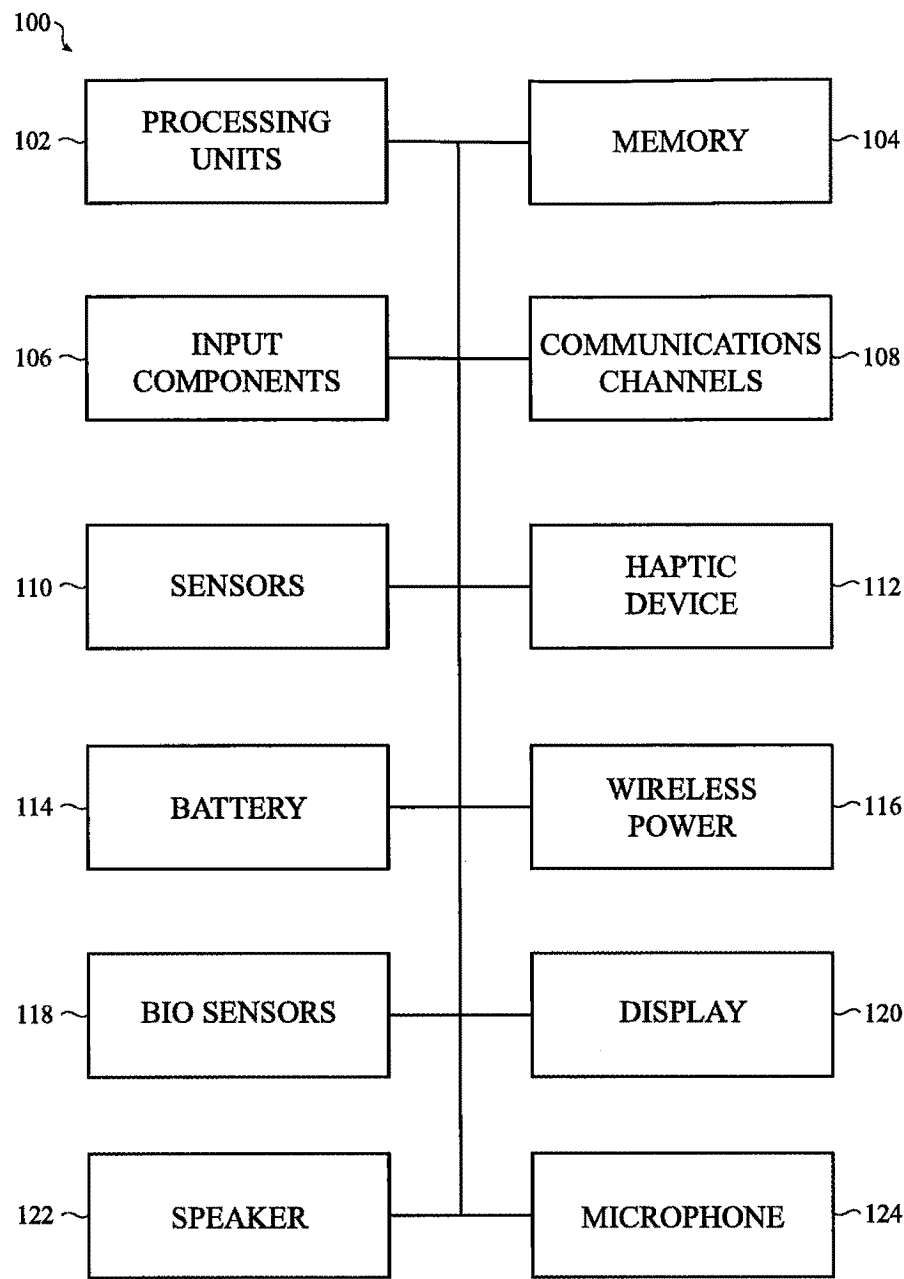


FIG. 2

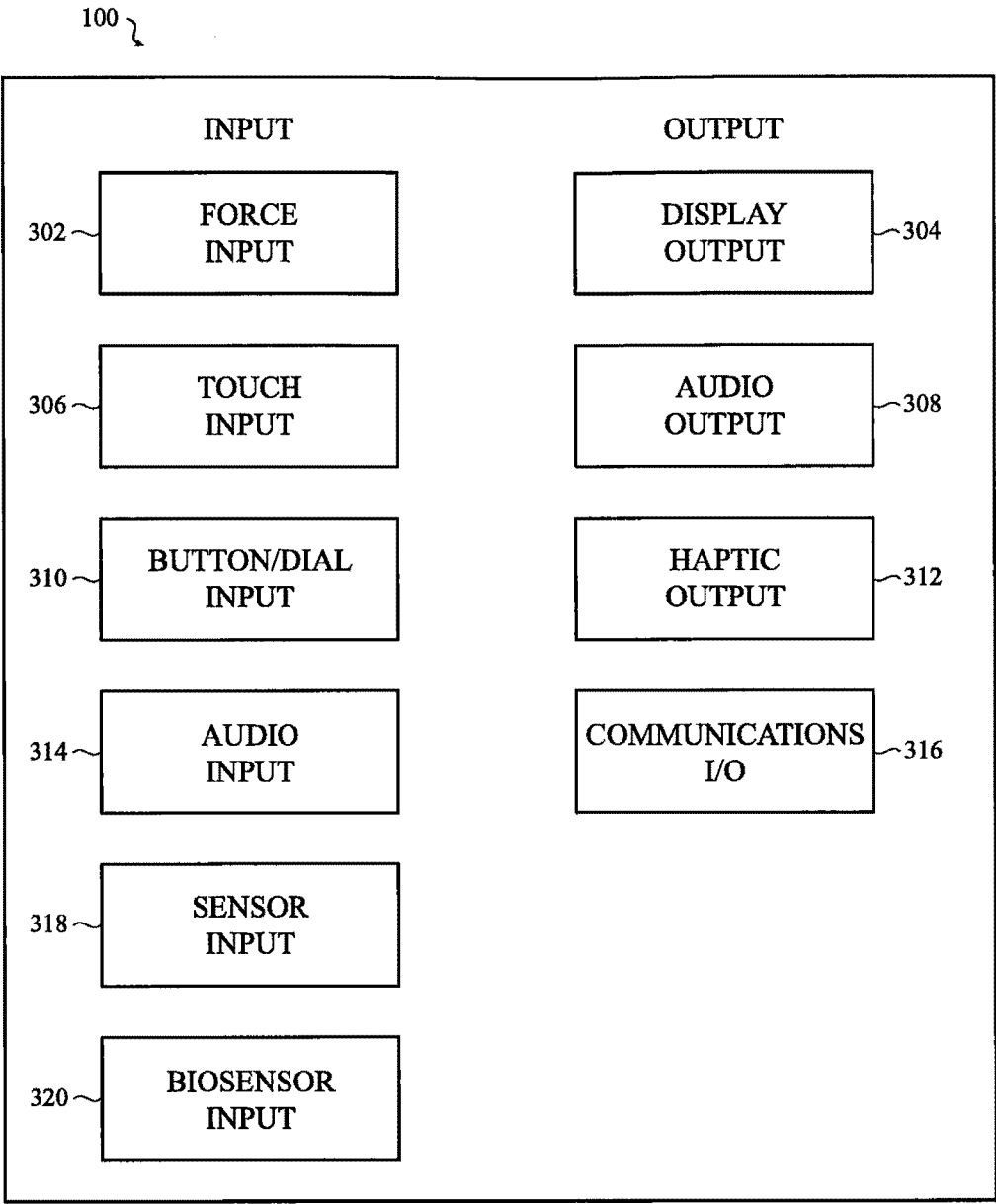
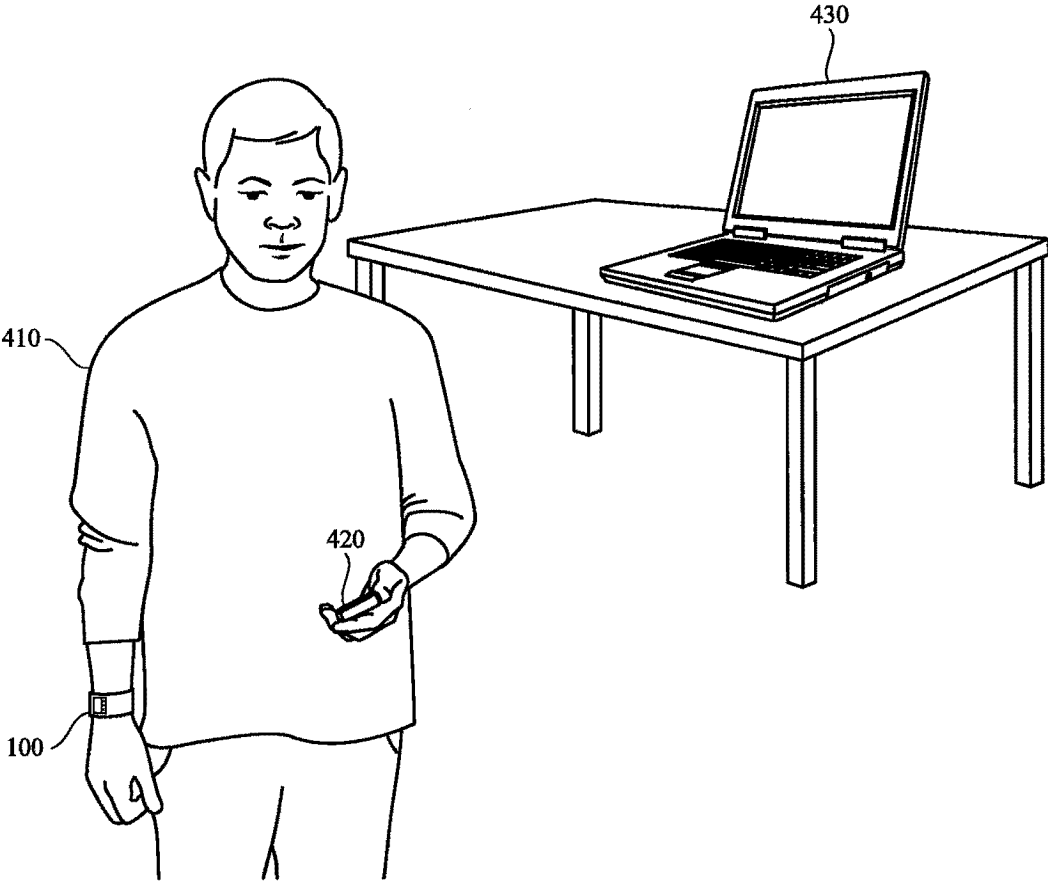


FIG. 3



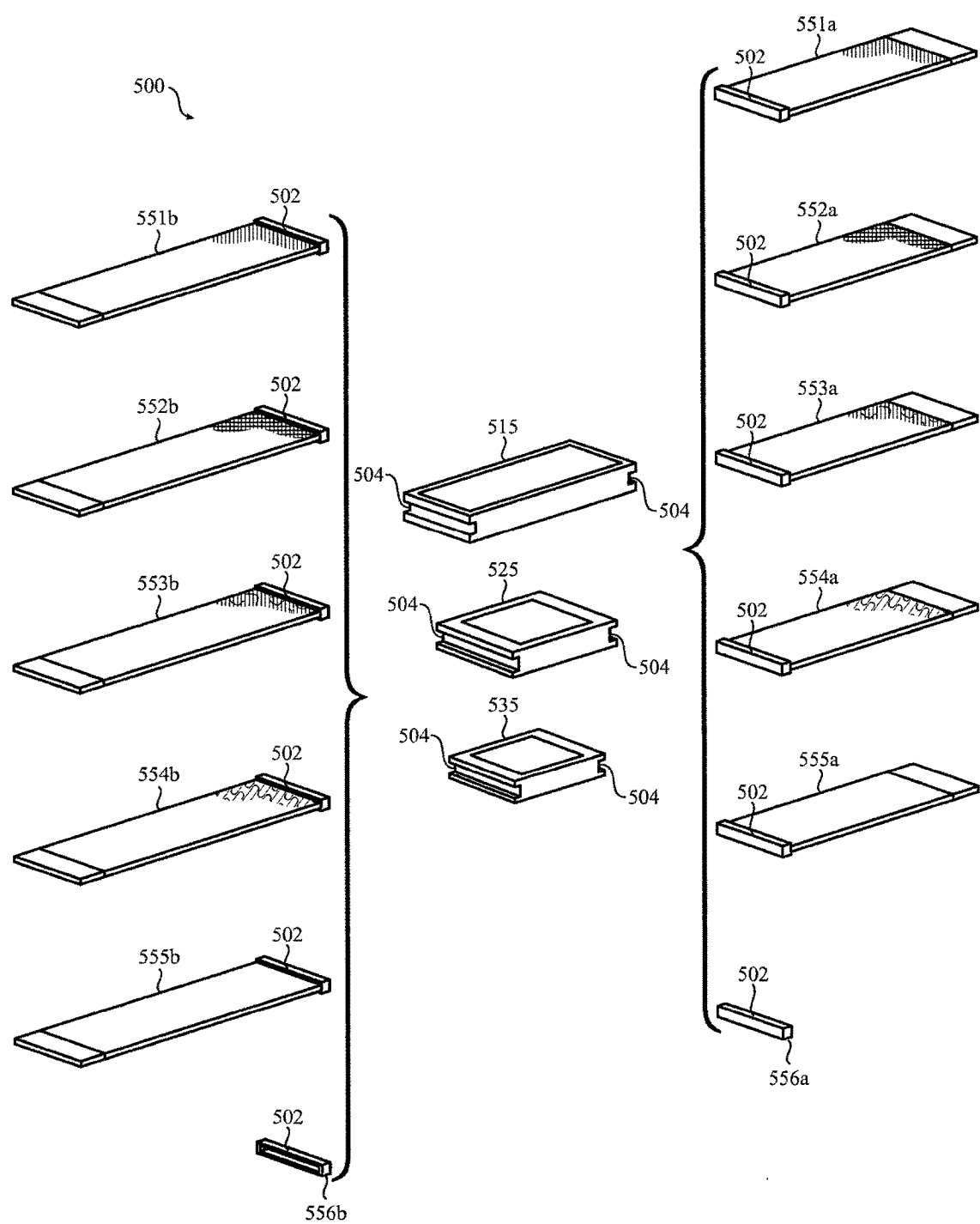
**FIG. 4**

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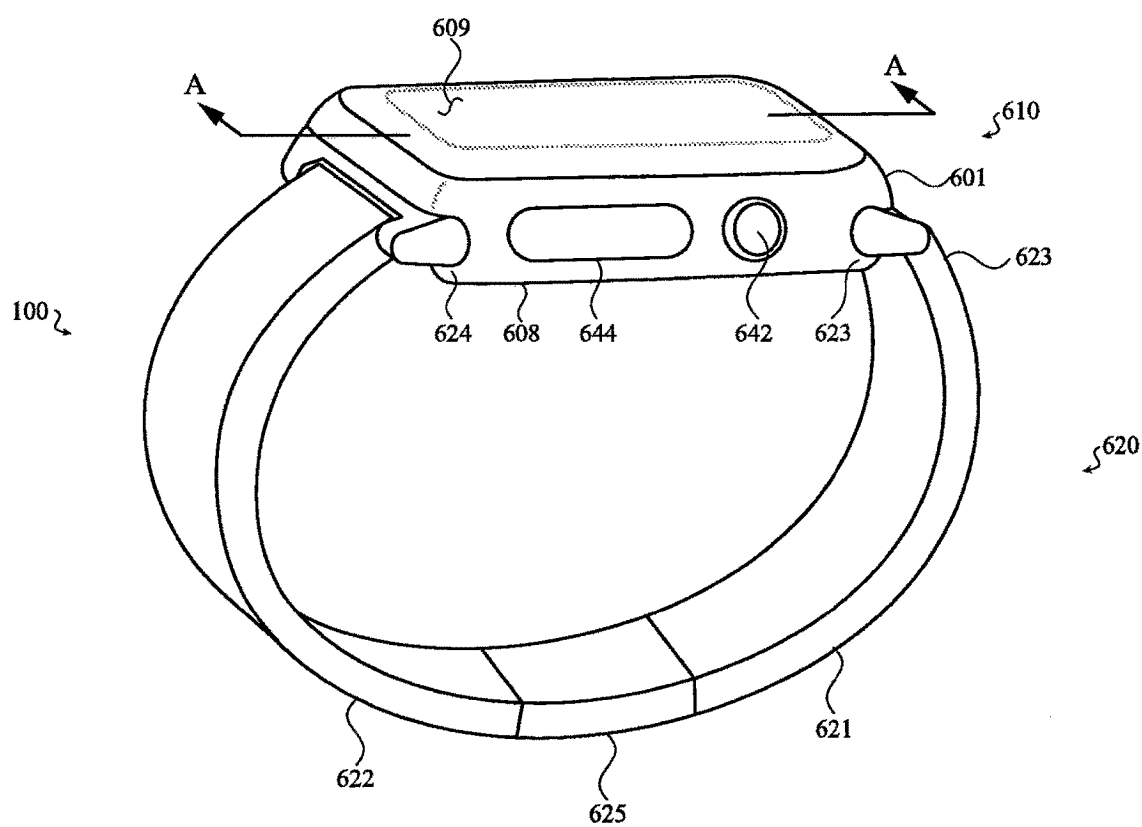


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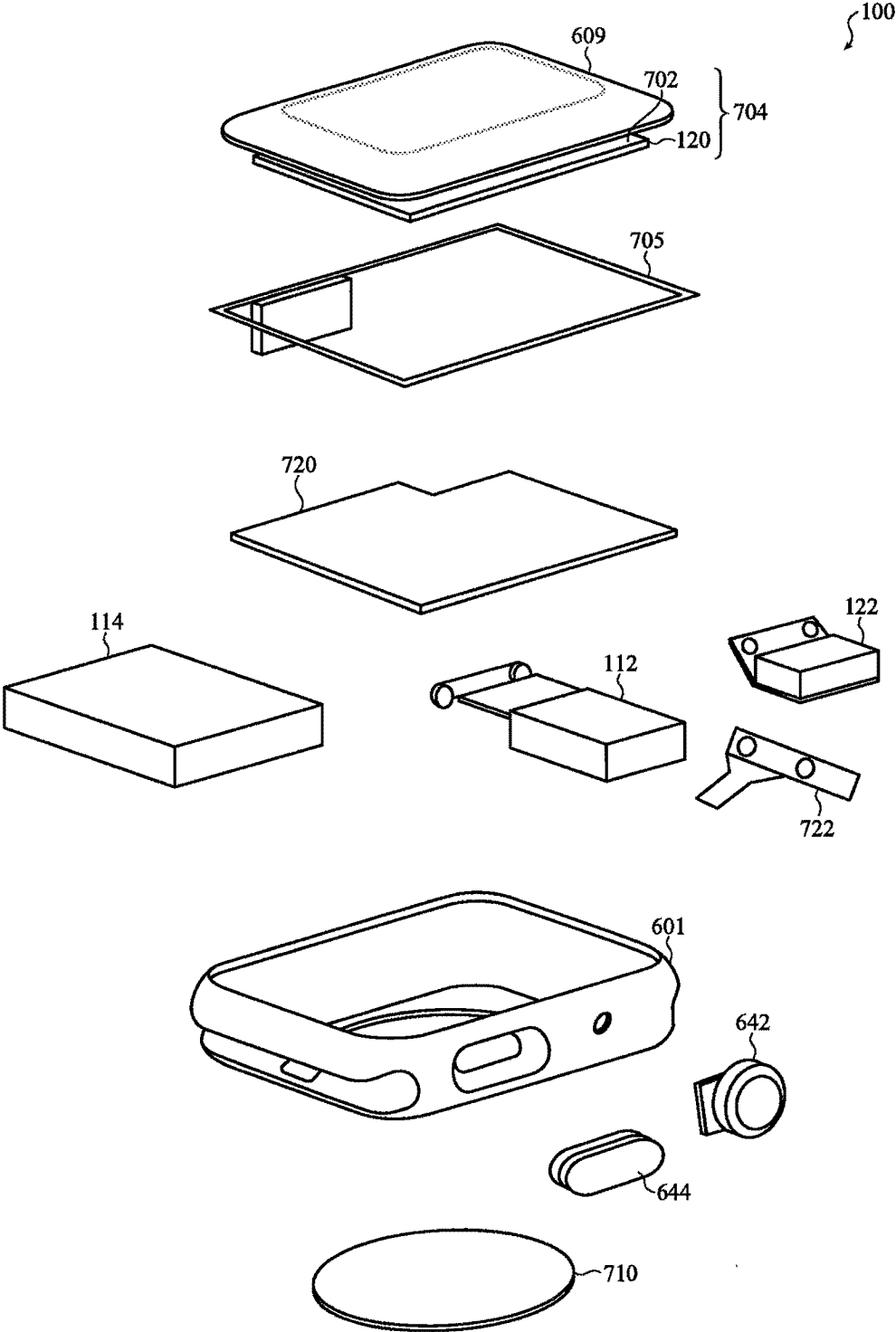


FIG. 7

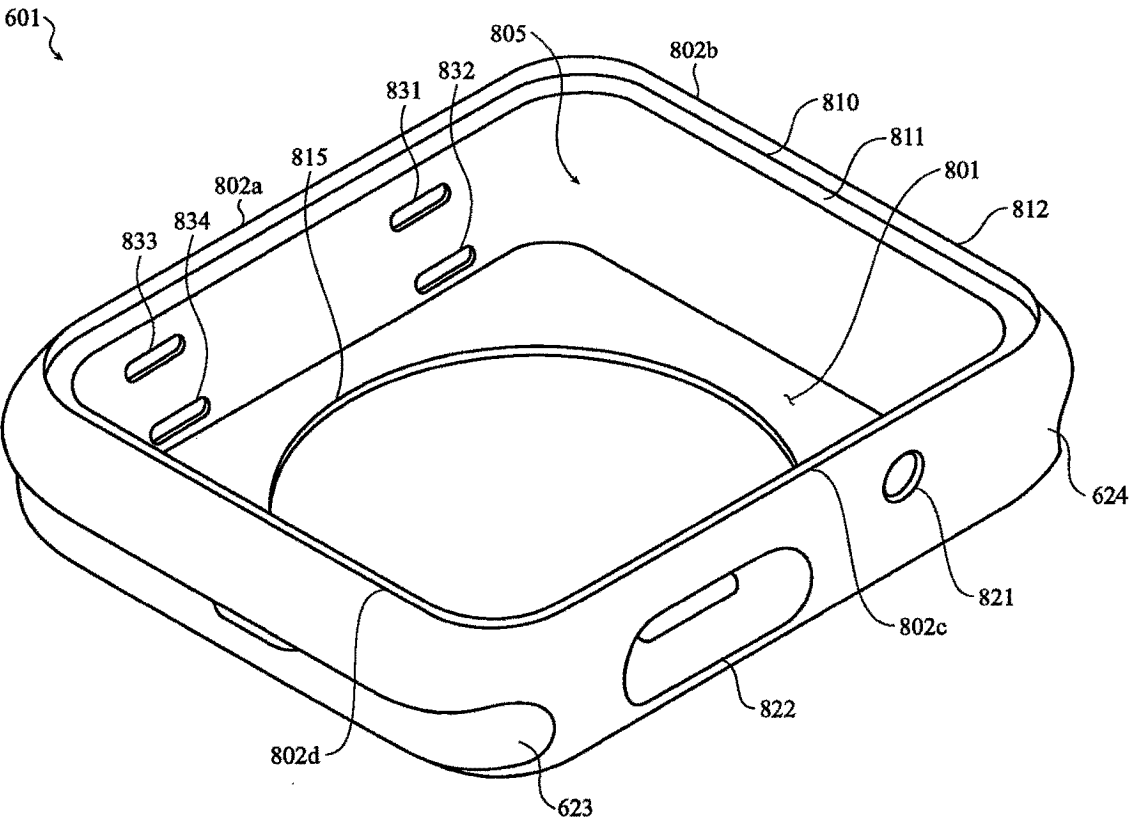


FIG. 8

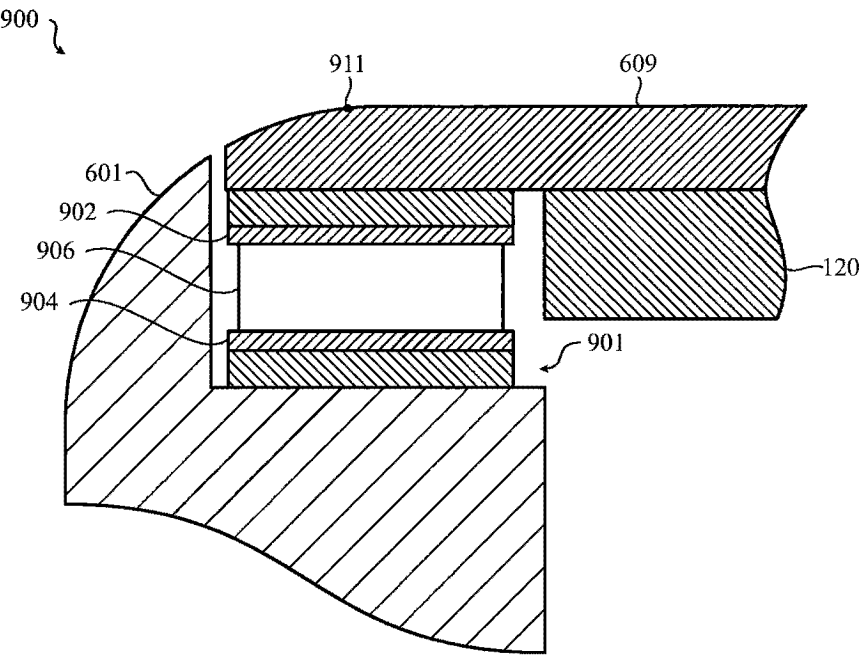


FIG. 9

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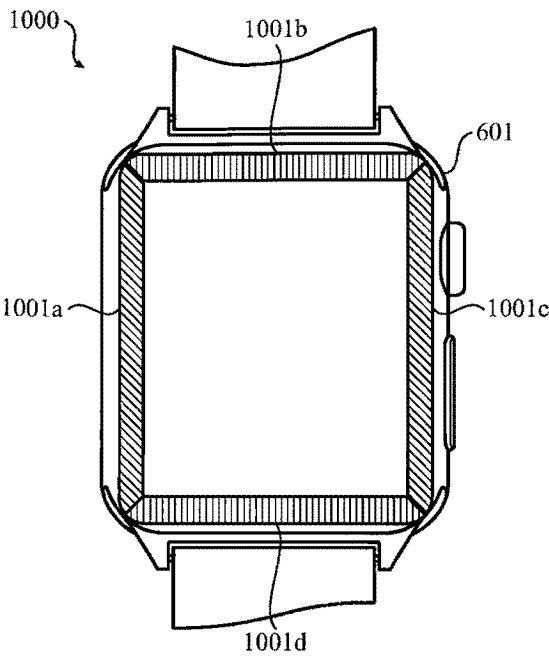


FIG. 10A

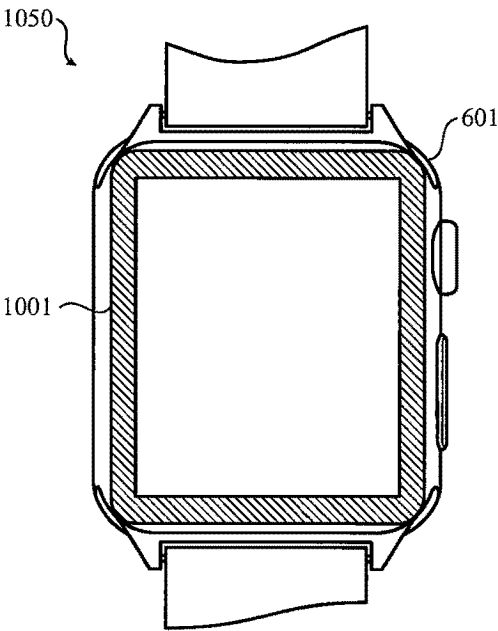


FIG. 10B

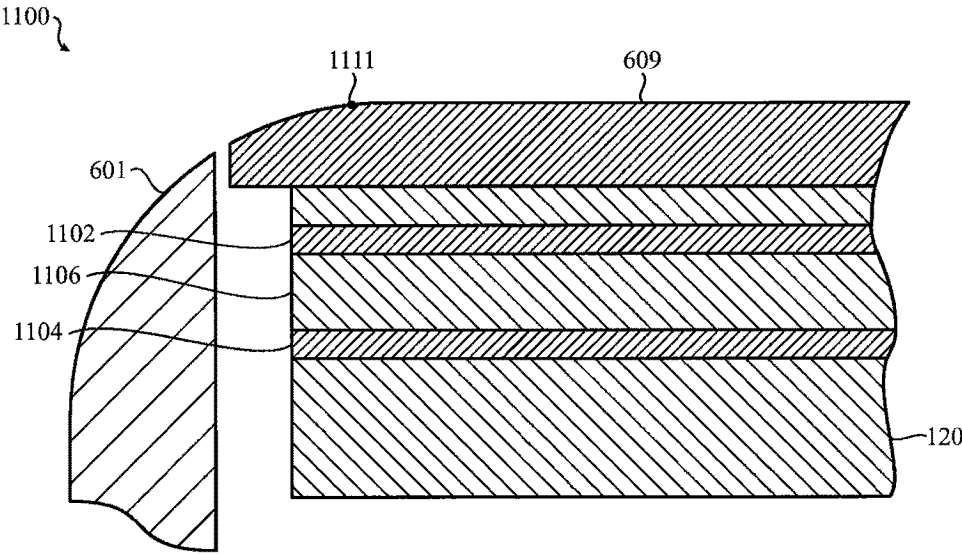


FIG. 11

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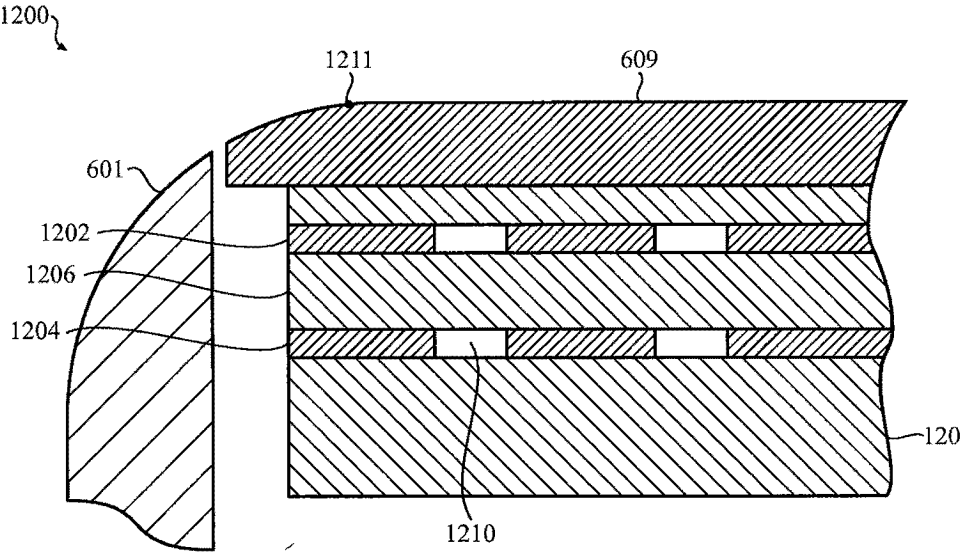


FIG. 12



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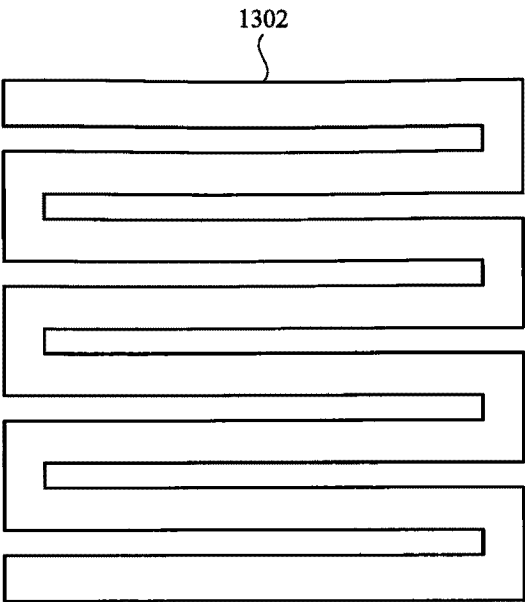


FIG. 13A

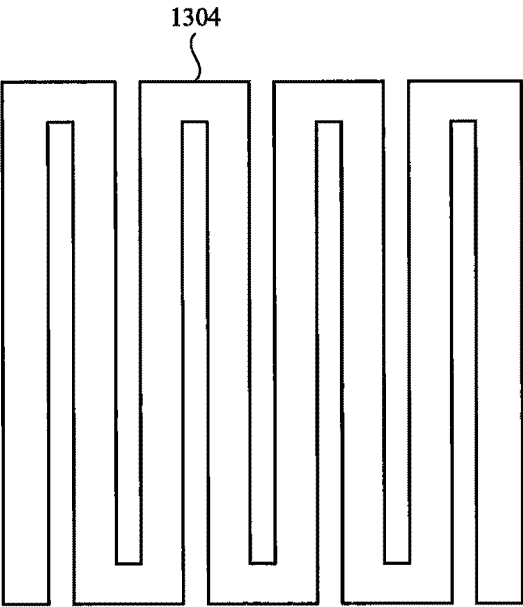


FIG. 13B

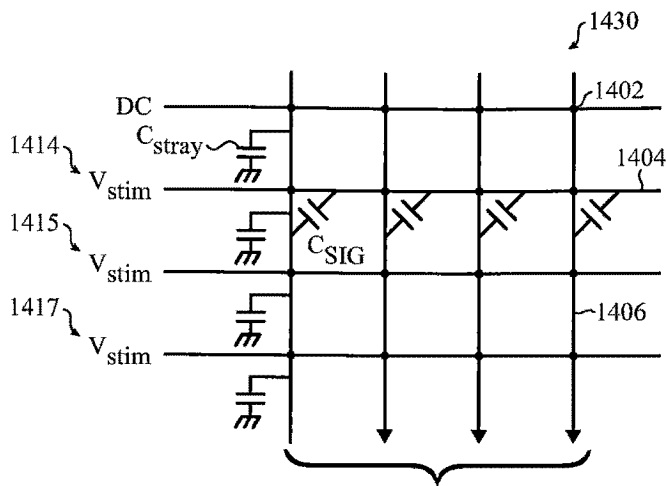


FIG. 14A

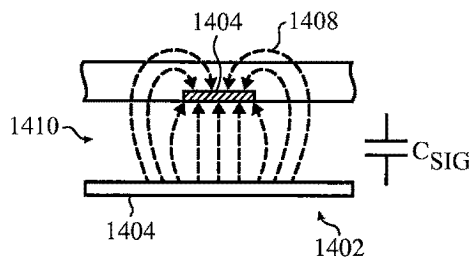


FIG. 14B

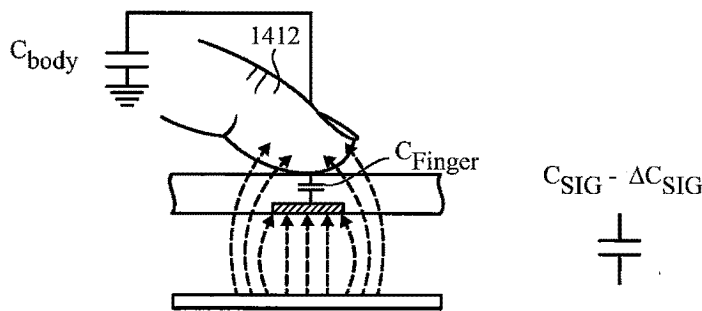


FIG. 14C

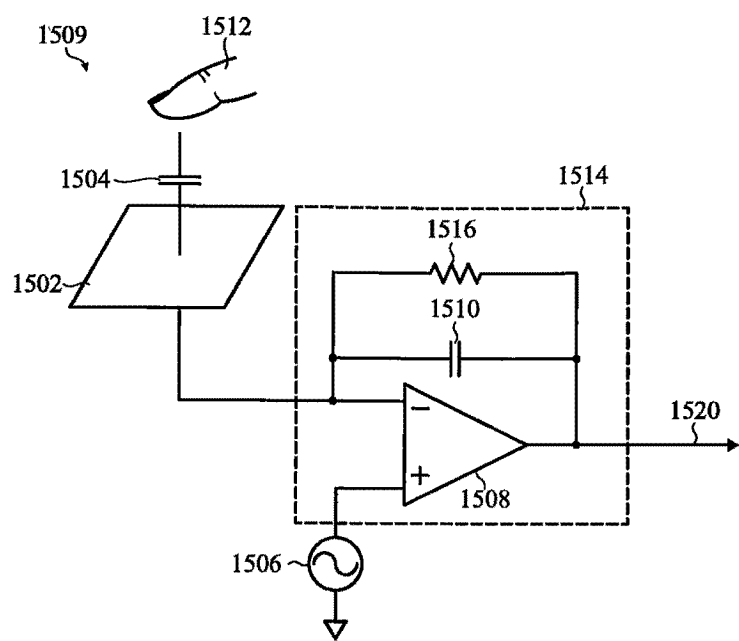


FIG. 15A

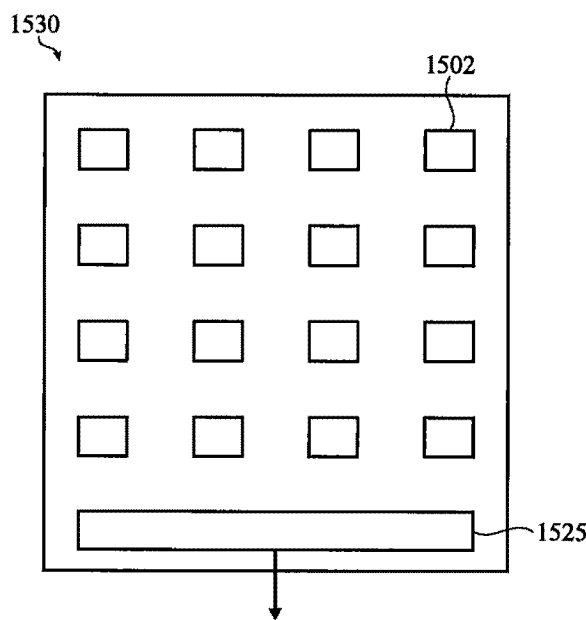


FIG. 15B

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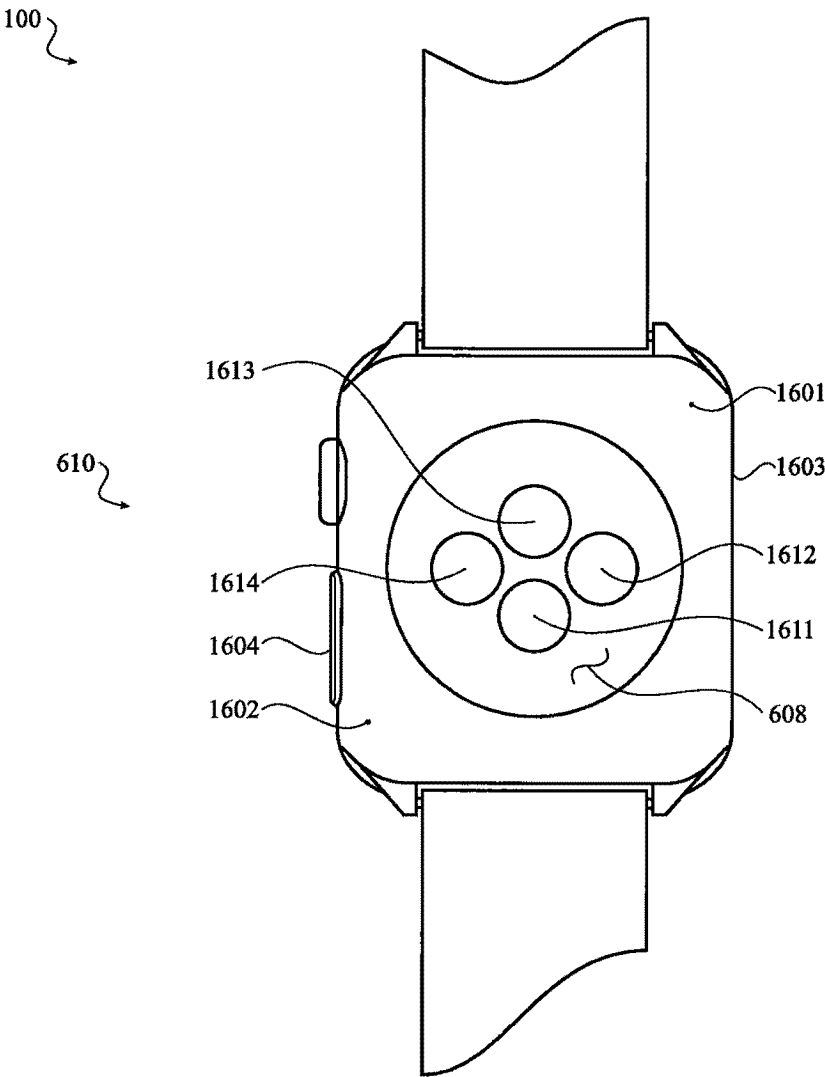


FIG. 16

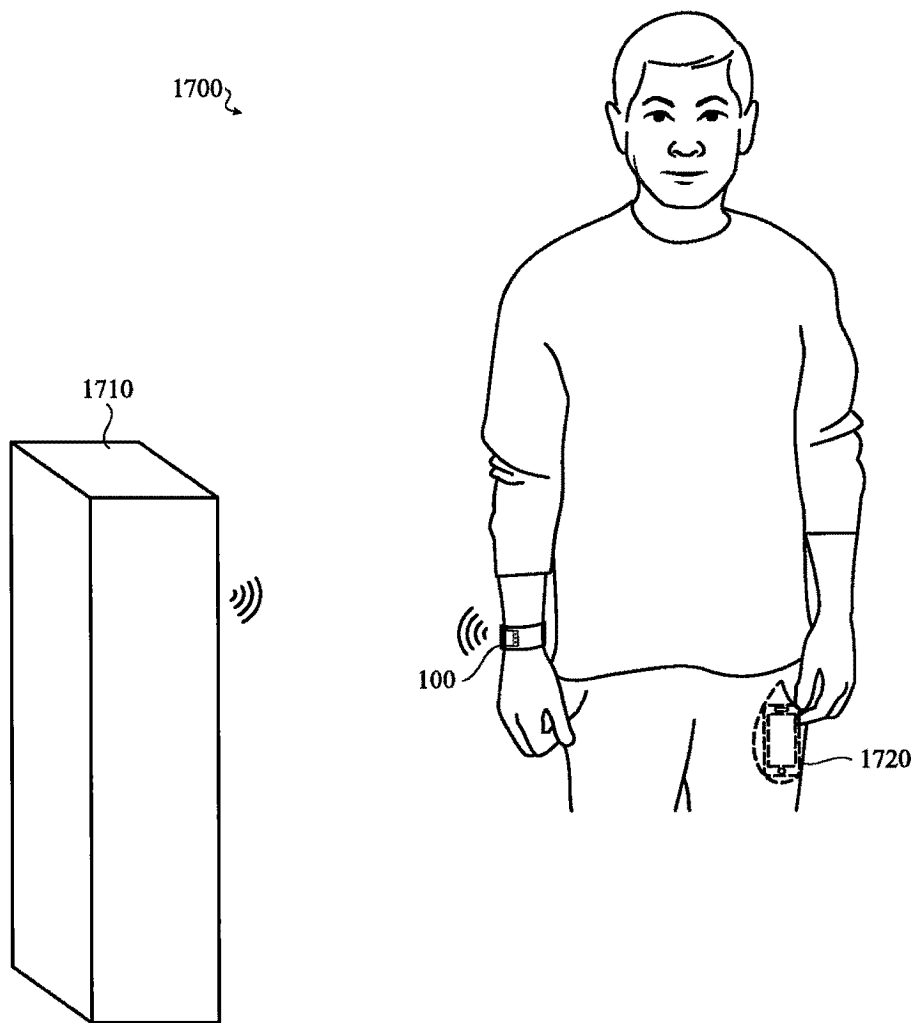


FIG. 17

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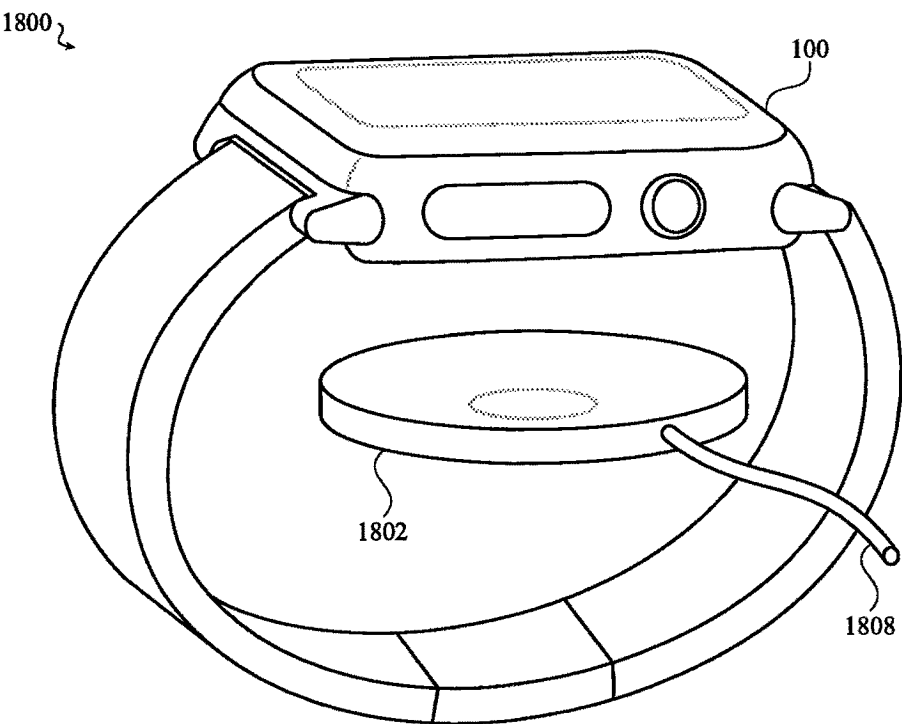


FIG. 18



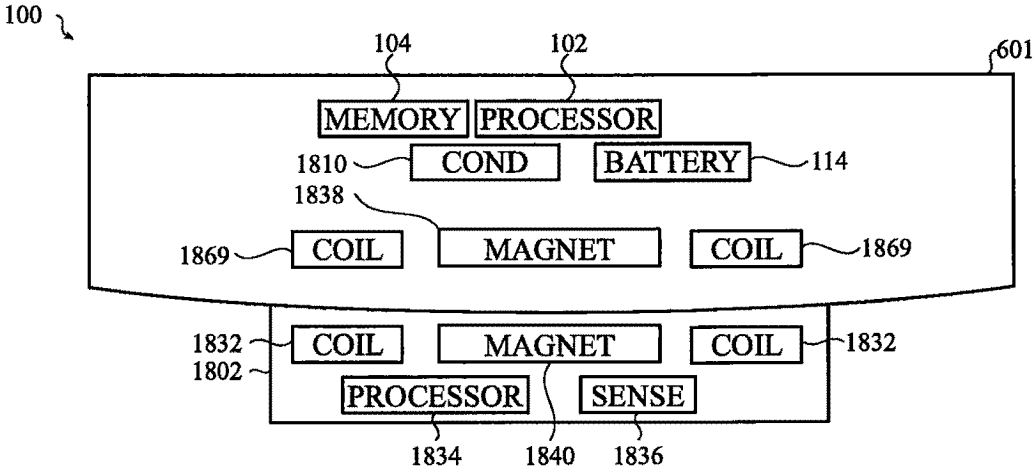


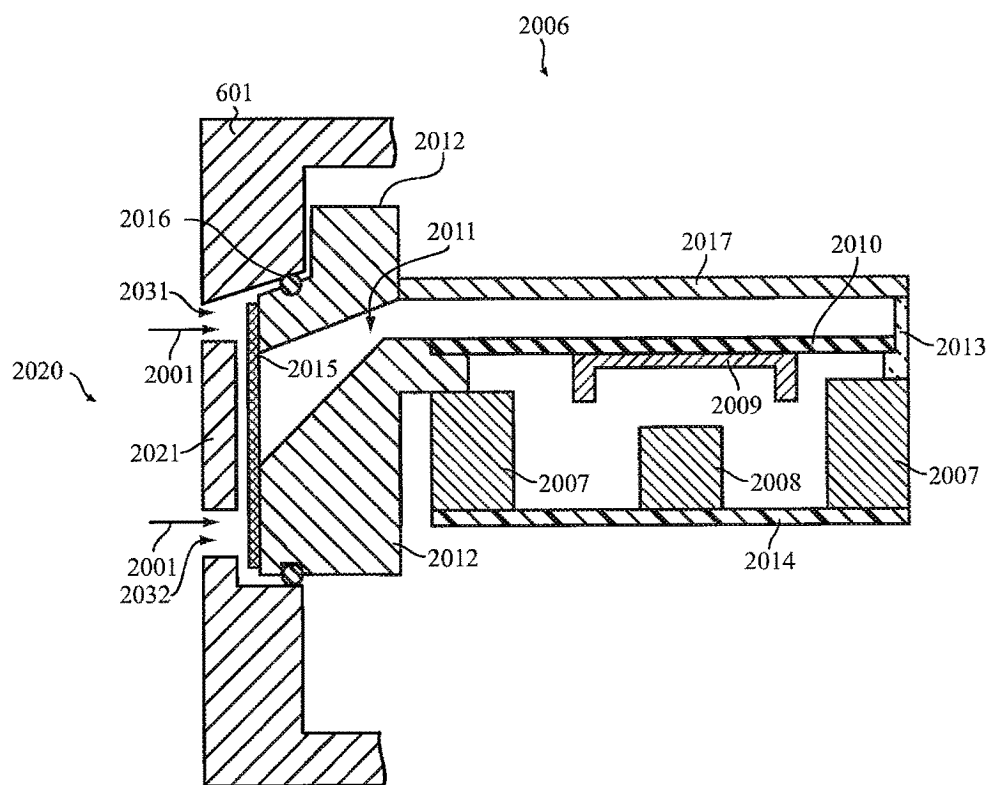
FIG. 19

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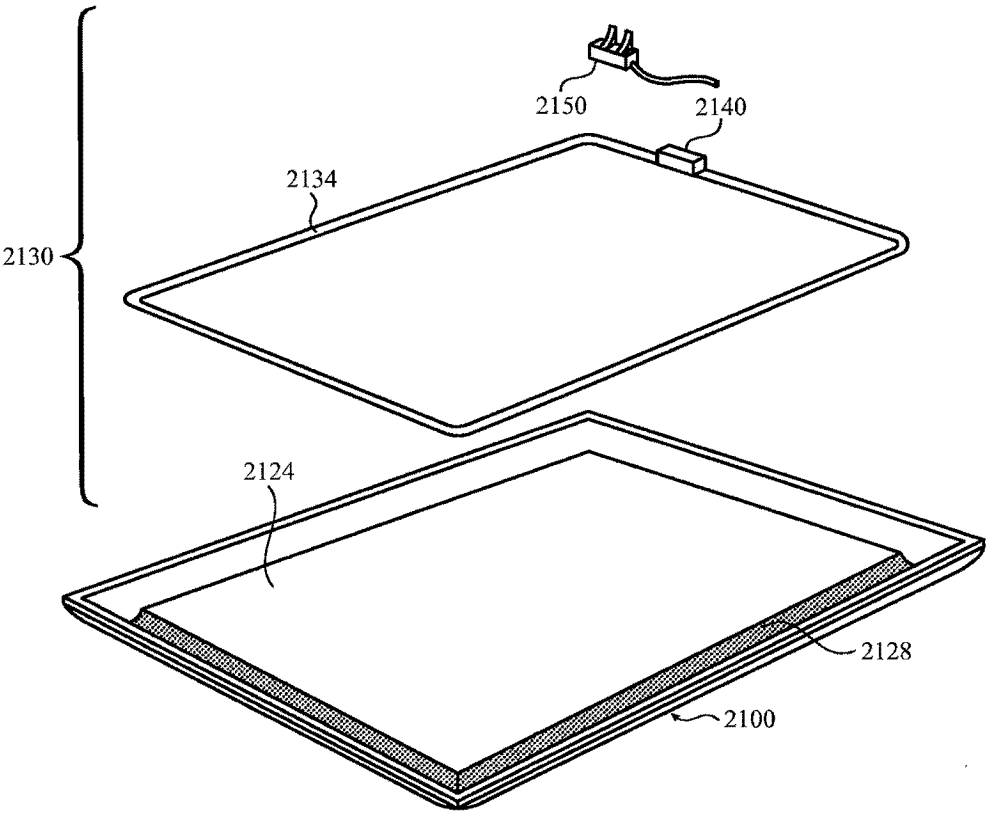


FIG. 21A

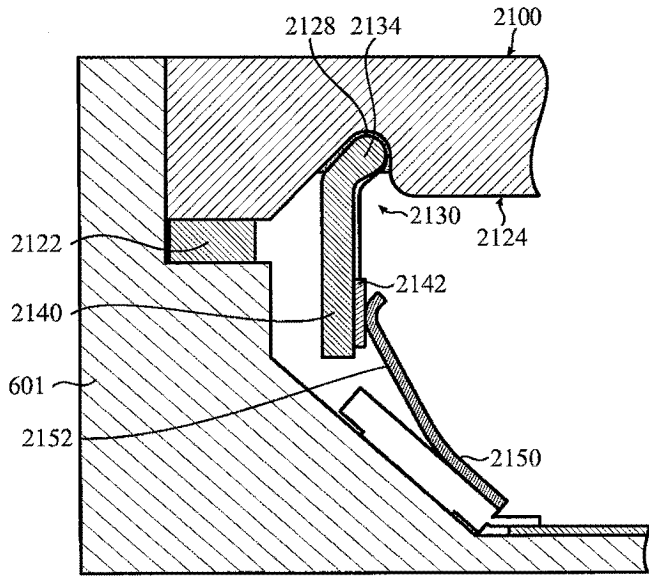


FIG. 21B

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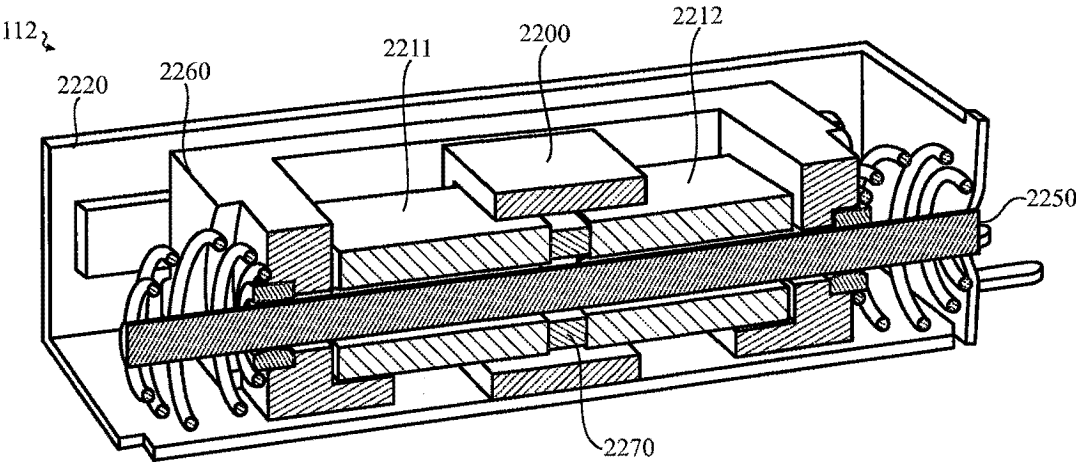


FIG. 22A

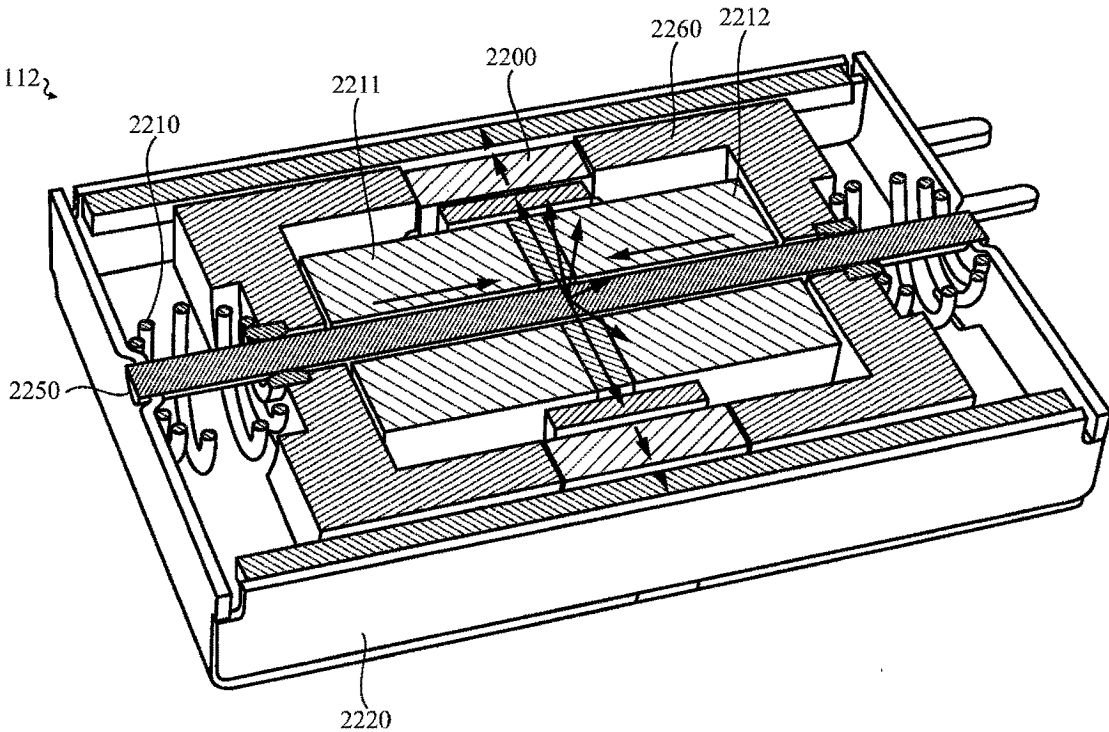


FIG. 22B

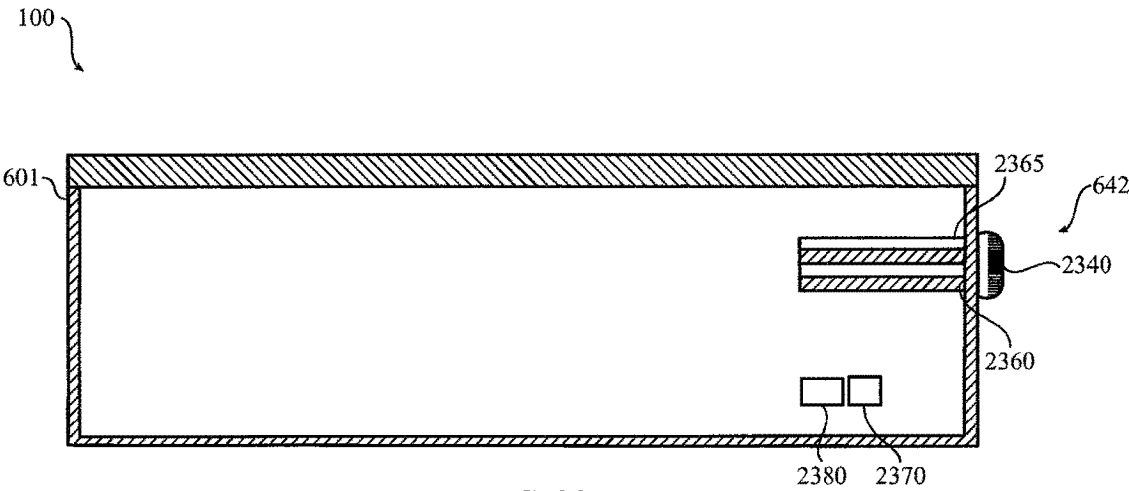


FIG. 23

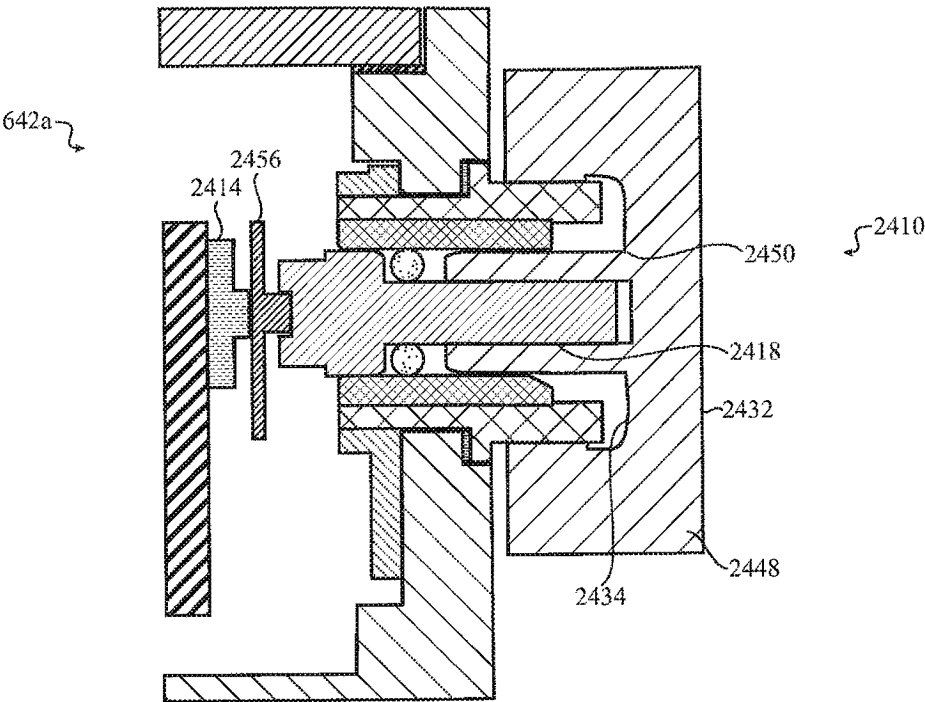


FIG. 24A

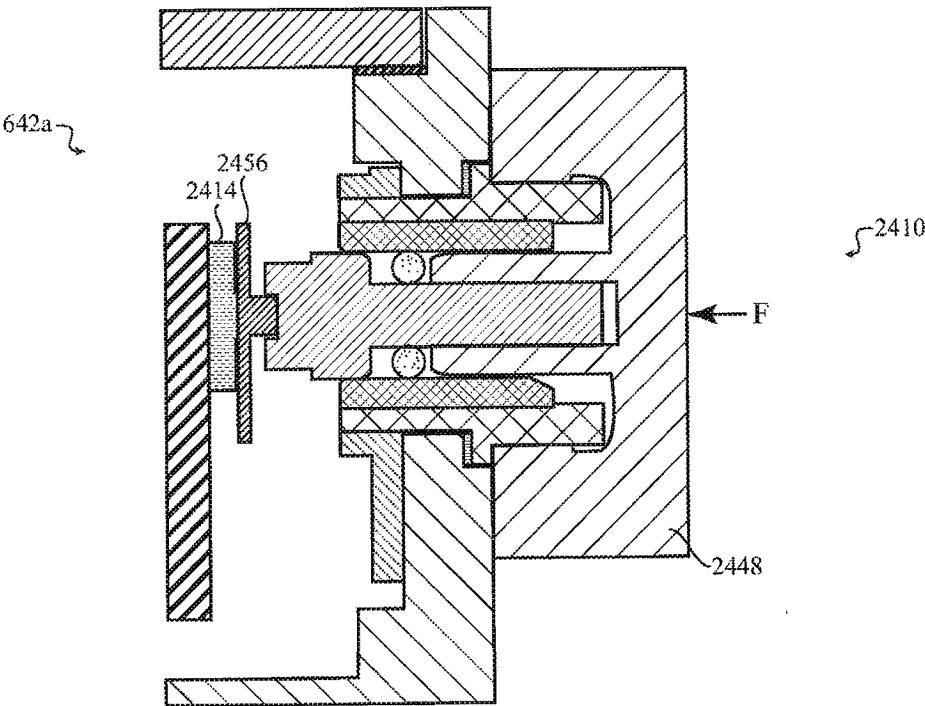


FIG. 24B



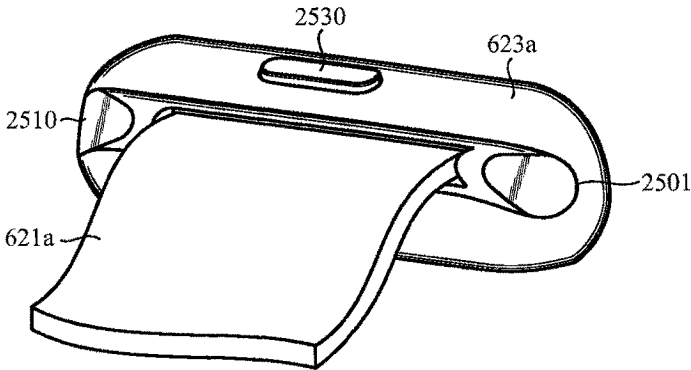


FIG. 25A

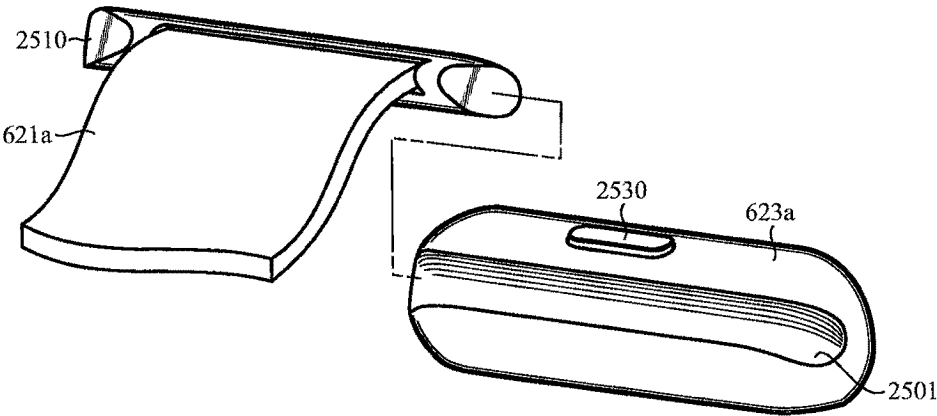


FIG. 25B

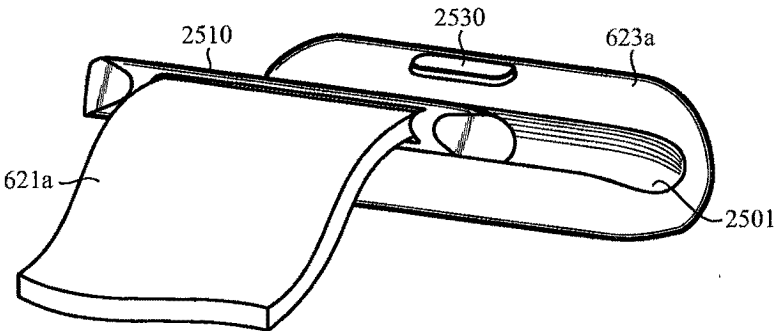


FIG. 25C

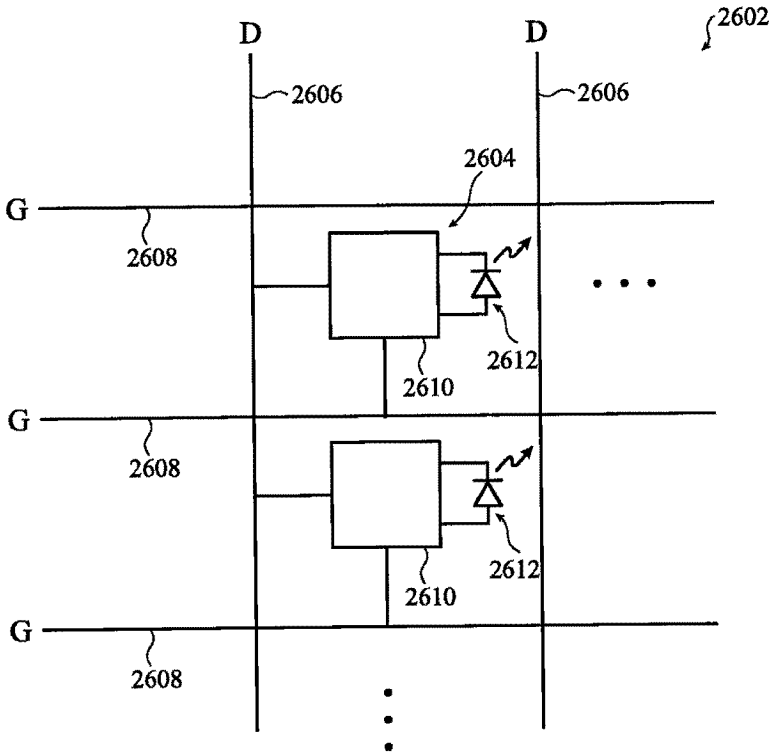


FIG. 26

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WEARABLE ELECTRONIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation patent application of U.S. patent application Ser. No. 15/261,912, filed Sep. 10, 2016, and titled "Wearable Electronic Device," U.S. patent U.S. patent application Ser. No. 15/261,917, filed Sep. 10, 2016, and titled "Wearable Electronic Device," and U.S. patent application Ser. No. 14/842,617, filed Sep. 1, 2015, and titled "Wearable Electronic Device," which is a non-provisional patent application of and claims the benefit of U.S. Provisional Patent Application No. 62/044,974, filed Sep. 2, 2014, and titled "Wearable Electronic Device and Associated Methods of Use and Manufacture," the disclosures of which are hereby incorporated herein by reference in their entireties.

FIELD

The following disclosure generally relates to an electronic device, and more specifically to a wearable electronic device having a range of features, including touch input, force input, an interchangeable attachment system, health monitoring functionality, wireless power charging, wireless authentication and transaction functionality, and other features and functionality.

BACKGROUND

Portable electronic devices have become increasingly popular, and the features and functionality provided by portable electronic devices continue to expand to meet the needs and expectations of many consumers. However, some traditional portable electronic devices, particularly wearable electronic devices, may have relatively limited functionality or are only able to perform a specialized set of functions or tasks. For example, some traditional electronic wristwatches may be configured to perform a relatively limited set of functions, including displaying time, date, and performing basic timing functions. The embodiments described herein are directed to a wearable electronic device that provides a wide range of functionality, as compared to some traditional wearable electronic devices.

SUMMARY

The embodiments included herein are directed to a consumer product, which may include a portable or wearable electronic device that is configured to provide an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device.

Some example embodiments are directed to wearable electronic device having a housing that includes a flat bottom portion, a top portion defining a cavity, and a curved side portion that extends from the bottom portion to the top portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A display may be at least partially disposed within the cavity and may have a viewable area. The device may also include

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a cover disposed above the display and including a flat middle portion larger than the viewable area of the display, a curved edge portion surrounding the flat middle portion and coinciding with the curved side portion along a perimeter of the cavity to form a continuous contoured surface.

In some embodiments, the continuous contoured surface is tangent with the flat bottom portion of the housing at a first end of the contour. The continuous contoured surface may also be tangent with the flat middle portion of the cover at a second end of the contour. In some embodiments, the continuous contoured surface has a constant radius.

In some embodiments, the cavity has a rectangular shape. The curved edge portion of the housing may have four sides that surround the cavity, each side is orthogonal to two adjacent sides. Each side may be connected to an adjacent side by a rounded corner. In some embodiments, the rounded corners have a curvature that corresponds to a curvature of the continuous contoured surface formed by the curved edge portion of the cover and the curved side portion of the housing.

Some embodiments include a crown module that is positioned at least partially within an aperture formed within the curved side portion of the housing. The crown module may include an outer surface configured to receive a rotary user input. The crown module may be offset with respect to a centerline of the housing between the top portion and the flat bottom portion. The offset may be toward the top portion of the housing. The crown module may include a dial having a portion that is higher than an interface between the cover and the housing.

In some example embodiments, a port is formed in the curved side portion of the housing. An acoustic module may be disposed within the housing and configured to produce an audio output through the port. The acoustic module may include an acoustic element and an acoustic cavity that acoustically couples the acoustic element to the port. The port may include an orifice that is offset with respect to the acoustic cavity to prevent the direct ingress of liquid into the acoustic module.

In some embodiments, the device includes a gasket positioned between the housing and the cover. The housing may also include a ledge formed along a perimeter of the cavity. The gasket may be positioned along the ledge that is formed along the perimeter of the cavity. The gasket, the cover, and the housing may be configured to cooperate to form a substantially water-proof seal.

In some example embodiments, the device includes a biosensor module that is disposed in an opening formed in the flat bottom portion of the housing. The biosensor module may include a chassis positioned in the opening of the housing and defining an array of windows. An array of light sources may be attached to the chassis and configured to emit light into the user through the array of windows. The biosensor module may also include an optically transparent rear cover disposed over the chassis and over the array of windows and operative to pass light emitted from the array of light sources into the user. In some embodiments, the rear cover has a convex outer contour.

Some example embodiments are directed to an electronic device having a housing comprising a bottom portion defining an opening and a band attached to the housing and configured to secure the electronic device to a user. A biosensor module may be disposed within the opening of the housing. A rear cover may be disposed over the biosensor module and may include an edge protruding outwardly from the bottom portion of the housing and an outer surface having a convex curved contour. In some embodiments, the

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outer surface of the rear cover defines one or more windows that provide operational access to one or more optical components of the biosensor module. The one or more windows may have a curvature that matches the convex curved contour of the outer surface.

In some embodiments, the biosensor module includes an array of light sources that are configured to emit light into a body of the user. The biosensor module may also include a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. In some cases, the biosensor module is removably coupled to the housing.

In some embodiments, the device also includes a processing unit configured to compute a health metric associated with the user based on the sensor signal. The device may also include a display disposed within the housing and configured to display the health metric.

Some example embodiments are directed to a wearable electronic device, having a housing including a top portion, a cavity formed within the top portion, and a curved side portion that surrounds the cavity. The device may also include a transparent cover disposed over the cavity of the housing and may include a flat middle portion at a center of the transparent cover, a curved outer portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge of the transparent cover, and a mask positioned relative to an internal surface of the transparent cover. The mask may have an outer boundary located proximate to the edge of the transparent cover and an inner boundary located within the curved outer portion of the transparent cover.

In some embodiments, the device includes a display disposed below the transparent cover. A perimeter portion of a viewable area of the display may be disposed below the mask. The device may also include an antenna having a shape that corresponds to a shape of the cavity formed within the housing. The antenna may be disposed in a groove formed in the internal surface of the transparent cover. The groove may be formed between the outer boundary and the inner boundary of the mask. In some embodiments, the cover is formed from a sapphire material. The antenna may be configured to facilitate wireless communication between the wearable electronic device and an external device.

Some example embodiments are directed to an electronic device having a housing including a first end, a second end opposite the first end, a first side extending between the first and second ends, and a second side opposite to the first side and extending between the first and second ends. The first end may define a first groove extending between the first and second sides and may be configured to receive a first lug portion of a first band. The second end may define a second groove extending between the first and second sides and may be configured to receive a second lug portion of a second band. The first and second grooves may have an inwardly curved concave shape with an undercut feature that retains the first and second lug portions. In some embodiments, the first groove extends through a solid portion of the housing to form a continuous interior shape.

In some embodiments, the device includes a display at least partially disposed within a cavity of the housing. A cover may be disposed above the display and at least a portion of the first groove is disposed below the cover. The first and second grooves may be formed at an angle with respect to a centerline of the housing. The first and second grooves may be angled upward toward a top of the housing and inward toward the center of the housing. The first and second grooves may cross the centerline of the housing.

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Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A crown may be disposed relative to the housing and configured to receive a rotational input. An encoder may be operatively coupled to the crown and configured to produce an encoder output that corresponds to the rotational input. A speaker module may be disposed within the housing and configured to produce an audio output that corresponds to the encoder output. A haptic device may be disposed within the housing and configured to produce a haptic output that corresponds to the encoder output. In some embodiments, the haptic output is synchronized with the audio output. The crown may be further configured to translate along an axis and actuate a tactile switch.

In some embodiments, the device also includes a display element within the housing. The device may be configured to display a list of items on the display element and scroll the list of items in response to the encoder output. The device may also be configured to synchronize the audio and haptic outputs with the scrolling of the list of items. In some embodiments, the crown is further configured to translate along an axis and actuate a tactile switch. The crown may be operative to select an item of the list of items when the tactile switch is actuated.

Some example embodiments are directed to a wearable electronic device having a housing that includes a bottom portion and an aperture formed in the bottom portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A biosensor module may be disposed in the aperture of the housing. The biosensor module may include an array of light sources configured to emit light into a body of the user, and a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. The device may also include a processing unit that is configured to compute a health metric associated with the user based on the sensor signal. A display may be disposed within the housing and configured to display the health metric.

In some embodiments, the array of light sources and the photodetector are configured to function as multiple photoplethysmography (PPG) sensors. Each PPG sensor may be configured to be used to compute a separate health metric. In some embodiments, a first light source of the array of light sources includes a green LED adapted to detect blood perfusion in the body. A second light source of the array of light sources may include an infrared LED adapted to detect water content of the body. The health metric may include one or more of: a heart rate, a respiration rate, a blood oxygenation level, and a blood volume estimate.

In some embodiments, the device also includes at least one pair of electrodes disposed on an exterior surface of the housing. The at least one pair of electrodes may be configured to produce a signal when the at least one pair of electrodes is in contact with the body. In some case, the signal is used to compute an additional health metric that includes one or more of: a heart function, a body fat estimate, and a body fat estimate.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. The device may also include an array of light emitting diodes (LEDs) disposed within the housing, the array of LEDs being configured to emit light. A photodetector may be disposed within the housing and configured



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to receive light produced by an LED of the array of LEDs that is reflected from a body of the user and produce a first sensor signal in response to the received light. The device may also include at least one pair of electrodes disposed on an exterior surface of the wearable electronic device. The electrodes may be configured to produce a second sensor signal when the electrodes are in contact with a respective portion of the body. The device may also include a processing unit that is configured to compute one or more health metrics based on the first and second sensor signals. The device may also include a display disposed at least partially within the housing and configured to display the one or more health metrics.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be disposed relative to the housing and a display may be attached to a lower surface of the cover. A force sensor may be positioned between the cover and the housing and attaching the cover to the housing. The force sensor may be configured to detect the force of a touch on the cover. The force sensor may also form a barrier to prevent ingress of liquid into the wearable electronic device. In some embodiments, an antenna may be disposed relative to the cover and external from the housing. The antenna may be configured to facilitate wireless communication with an external device.

In some example embodiments, a wearable electronic device may include a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A display element may be positioned within the housing and a rechargeable battery may be disposed within the housing and operatively coupled to the display element. The device may also include a receive coil within the housing configured to inductively couple with an external transmit coil. A power conditioning circuit may be configured to recharge the rechargeable battery using power received by the receive coil. The power conditioning circuit may be configured to provide power to the display element. The device may also include a first alignment magnet positioned within the receive coil and configured to align the device with respect to a second alignment magnet positioned within the external transmit coil.

Some example embodiments are directed to a wearable electronic device that includes a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be positioned relative to the housing and a display may be disposed within the housing and below the cover. A force sensor may be disposed within the housing and configured to detect a force of a touch on the cover. A touch sensor may be disposed between the display and the cover. The touch sensor may be configured to detect a location of the touch on the cover. In some embodiments, the force sensor is disposed along a perimeter of the display. The device may also include a processing unit and memory disposed within the housing. The processing unit may be configured to interpret a touch gesture on a surface of the cover using a force output from the force sensor and a touch output from the touch sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements.

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FIG. 1 depicts an example wearable electronic device having a device body and band.

FIG. 2 depicts an example schematic diagram of a wearable electronic device.

FIG. 3 depicts an example functional diagram for a wearable electronic device.

FIG. 4 depicts an example wearable electronic device as part of a system of devices.

FIG. 5 depicts a system of interchangeable components for a wearable device.

FIG. 6 depicts an example wearable electronic device having a device body and band.

FIG. 7 depicts an exploded view of components of an example wearable electronic device.

FIG. 8 depicts an example housing for a wearable electronic device.

FIG. 9 depicts an example force sensor configured to use a capacitive measurement.

FIGS. 10A-B depict plan views of example force sensors.

FIG. 11 depicts an example force sensor configured to use a resistive measurement.

FIG. 12 depicts an example pixelated force sensor configured to use a resistive measurement.

FIGS. 13A-B depict example force sensor structures.

FIGS. 14A-C depict an example touch sensor based on mutual capacitance.

FIGS. 15A-B depict an example touch sensor based on self capacitance.

FIG. 16 depicts an example device having biosensors.

FIG. 17 depicts an example device having wireless communications with an external device.

FIG. 18 depicts an example electronic device and example dock of an inductive charging system.

FIG. 19 depicts a block diagram of an example inductive charging system.

FIG. 20 depicts an example acoustic module.

FIGS. 21A-B depict an example cover and antenna.

FIGS. 22A-B depict an example haptic module.

FIG. 23 depicts an example device having a crown module with an encoder.

FIGS. 24A-B depict an example device having a crown module with a tactile switch.

FIGS. 25A-C depict an example receiving feature for a band.

FIG. 26 depicts example elements of a display.

DETAILED DESCRIPTION

Provided herein are descriptions and examples of a consumer product, which may include a portable electronic device, a wearable electronic device, or other type of device. By way of example and not by way of limitation, the consumer product may be an electronic device, a mechanical device, or an electromechanical device. Specific example devices include mobile phones, personal digital assistants, music players, timekeeping devices, health monitoring devices, tablet computers, laptop computers, glasses (electronic or otherwise), portable storage devices, and the like.

In one particular embodiment, the consumer product is a portable and, more specifically, a wearable consumer product. A wearable consumer product is one that can be worn by or otherwise secured to a user. For example, the consumer product may be a wearable electronic device including, but not limited to, a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and the like. A wearable consumer product may be worn by a user in a variety of

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ways. In some examples, the consumer product is a wrist-worn product and may include a band that can be wrapped around a user's wrist to secure the consumer product to the user's body. The device may include one or more other types of attachments including, for example, an armband, lanyard, waistband, chest strap, and the like.

Some aspects of the disclosure are directed to a wearable electronic device having improved functionality and/or versatility as compared to some traditional wearable devices. For example, some aspects of the disclosure are directed to a consumer product, such as a portable electronic device, having an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device. Some aspects of the following disclosure are directed to the integration of a variety of subsystems or modules to provide functionality that may not be possible using some traditional device platforms. In some cases, the configuration and/or functionality provided by the various subsystems may be configurable by the end user, the manufacturer, and/or a vendor of the device. Example subsystems or modules of a consumer product and their respective functions are described below with respect to FIGS. 2 and 3.

Some aspects of the disclosure are directed to a consumer product that is configured to communicate wirelessly with any of a number of other devices, such as a mobile phone, computer, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Through wireless communication with other devices, the consumer product may transmit and/or receive various notifications, messages, or other information between devices. The wireless communication may also facilitate the relay of alerts or other device outputs to notify the user of an event or action. In some aspects, the consumer product may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. An example communication system is described below with respect to FIG. 4 and with respect to other examples provided herein.

In some aspects, the consumer product may include a system of interchangeable components used to attach or secure the consumer product to the user. The system of interchangeable components may include a set of interchangeable bands or attachment devices that are configured to connect or attach to a receiving feature on the body of the product. The receiving feature may be standardized within the system of interchangeable components and allow multiple types of bands or attachment devices to be used with the same housing or body. The system of interchangeable components may also allow for an interchange between different bodies, which may include different types of electronic devices or other consumer products. Each body of the different devices or products may have a similar receiving feature that is standardized within the system of interchangeable components. An example system of interchangeable components is described below with respect to FIG. 5 and with respect to other examples provided herein.

Some aspects of the present disclosure are directed to a consumer product that includes a body that includes a case or housing used to protect as well as support the internal

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components of the product in their assembled position. The housing may enclose and support various components, including, for example, integrated circuits, subsystems, modules, and other internal components of the device. In some aspects, the housing forms a water-resistant or waterproof barrier and also provides structural rigidity necessary to protect internal components. The housing may be formed as a single piece, which may enhance the structural rigidity, water impermeability, and manufacturability of the housing. An example housing and example internal components for a consumer product are provided below with respect to FIGS. 6-8 and with respect to other examples provided herein.

In some aspects, the consumer product includes a force sensor that is configured to detect and measure the magnitude of a force or pressure on a surface of the product. In some implementations, the force sensor includes a capacitive-based sensor that is configured to estimate the force based on a deflection or movement between capacitive plates that is caused by and correlates to the amount of force caused by a touch. In some implementations, the force sensor is a resistance- or charge-based sensor that is configured to estimate the force based on the deflection of a sheet or film that is positioned relative to the touch-sensitive surface of the product. In some implementations, the output from the force sensor is combined with the output from a touch sensor, which may be self-capacitive or mutually capacitive, or a combination of the two. Example force and touch sensors are described below with respect to FIGS. 9-15B and with respect to other examples provided herein.

In some aspects, the consumer product includes one or more biosensors. The biosensors may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. Example health metrics include, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. In some embodiments, the biosensors include an electrical sensor that may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. An example consumer product having multiple biosensors is described below with respect to FIG. 16 and with respect to other examples herein.

In some aspects, the consumer product is configured to perform wireless communication with an external device. In some implementations, the wireless communication may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce. An example consumer product having wireless communications with an external device is described in more detail below with respect to FIG. 17 and with respect to other examples herein.

In some aspects, the consumer product is configured to recharge an internal battery using a wireless charging system. In some implementations, the consumer product includes one or more receiving inductive coils that are configured to cooperate with one or more transmitting inductive coils that are located in a charging dock or other external device. The wireless charging system may allow the transfer of power and/or wireless communications with the consumer product without the use of an external port or terminal connection. An example consumer product having wireless charging capabilities is described in more detail below with respect to FIGS. 18-19 and with respect to other examples herein.



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In some aspects, the consumer product includes one or more acoustic modules that are configured to function as a speaker and/or a microphone for the product. The speaker and/or microphone may include features that enhance the water/liquid resistance or impermeability of the consumer product. The consumer product may also include a haptic module or actuator that is configured to produce a haptic output that may be perceived by the user. In some implementations, the output of an acoustic module, such as a speaker, and the haptic module may be used to provide feedback or an alert to the user. In some cases, an acoustic module and the haptic module provide feedback to the user and may be coordinated with a user input, such as user-interface selecting, user-interface scrolling, or other user input command. An example acoustic module is described below with respect to FIG. 20 and an example haptic module is described below with respect to FIGS. 22A-B.

In some aspects, the consumer product includes a dial or crown that is coupled to an encoder or other rotary sensor for detecting a rotary input. In some implementations, the output from the optical encoder is used to drive an aspect of a user interface or control other functionality of the product. Additionally, the dial or crown may include a tactile switch that can be actuated by pressing inward on the dial or crown. An example consumer product having a crown is described below with respect to FIGS. 23-24B and with respect to other examples herein.

The description that follows includes sample devices, components, modules, systems, methods, and apparatuses that embody various elements of the present disclosure. However, it should be understood that various elements of the described disclosure may be combined and/or practiced in a variety of forms in addition to those described herein. In particular, the modules and components are described in a particular combination with respect to some examples provided below. However other combinations are possible, which may be achieved by adding, removing, and/or rearranging modules to obtain a device or system having the desired characteristics.

FIG. 1 depicts a wearable consumer product 10. For example, the consumer product 10 may be a wearable electronic device. In one example, the consumer product 10 may be a wearable multifunctional electronic device including multiple functionalities such as time keeping, health monitoring, sports monitoring, medical monitoring, communications, navigation, computing operations, and/or the like. The functionalities may include but are not limited to: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating (in a wired or wireless fashion) with other electronic devices or services, which may be different types of devices having different functionalities; providing alerts to a user, which may include audio, haptic, visual and/or other sensory output, any or all of which may be synchronized with one another; visually depicting data on a display; gathering data from one or more sensors that may be used to initiate, control, or modify operations of the device; determining a location of a touch on a surface of the device and/or an amount of force exerted on the device, and using either or both as input; accepting voice input to control one or more functions; accepting tactile input to control one or more functions; capturing and transmitting images; and so on. These and other functions and features will be described in more detail herein.

The wearable consumer product 10 can take a variety of forms. In one example, the consumer product 10 may be a wrist-worn electronic device. The device may include a

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variety of types of form factors including, wristbands, armbands, bracelets, jewelry, and/or the like.

In the illustrated embodiment, the consumer product 10 includes a device body 11. The device body 11 may include a housing that carries, encloses and supports both externally and internally various components (including, for example, integrated circuit chips and other circuitry) to provide computing and functional operations for the consumer product 10. The components may be disposed on the outside of the housing, partially within the housing, through the housing, completely inside the housing, and the like. The housing may, for example, include a cavity for retaining components internally, holes or windows for providing access to internal components, and various features for attaching other components. The housing may also be configured to form a water-resistant or water-proof enclosure for the body 11. For example, the housing may be formed from as a single unitary body and the openings in the unitary body may be configured to cooperate with other components to form a water-resistant or water-proof barrier.

Examples of components that may be contained in the device body 11 include processing units, memory, display, sensors, biosensors, speakers, microphones, haptic actuators, batteries, and so on. In some cases, the device body 11 may take on a small form factor. In cases such as these, the components may be packaged and/or in order to provide the most functionality in the smallest space. The components may also be configured to take up a minimal amount of space, which may facilitate the device body 11 having a small form factor. Additionally, the integration and assembly of the various components may be configured to enhance the reliability of the consumer product 10.

The construction of the housing of the device body 11 may be widely varied. For example, housing may be formed from a variety of materials including plastic, rubber, wood, silicone, glass, ceramics, fiber composites, metal or metal alloys, (e.g., stainless steel, aluminum), precious metals (e.g., gold, silver), or other suitable materials, or a combination of these materials.

Also in the illustrated embodiment, the wearable electronic device includes a band 12 or strap or other means for attaching to a user. The band 12 may, for example, be configured to attach to the body and provide a loop for securing to the wrist of the user. The band 12 may be integral with the housing or it may be a separate part. If integral, the band 12 may be a continuation of the housing. In some cases, the integral band may be formed from the same material as the housing. If the band 12 is separate, the band may be fixed or releasably coupled to the housing. In both cases, the band 12 may be formed from similar or different materials as the housing. In most cases, the band 12 is formed from a flexible material such that it can conform to a user's body. Furthermore, the band 12 itself may be a single integral part or it may include attachment ends that provide an open and closed configuration. The attachment ends may, for example, be manifested as a clasp or other similar attachment mechanism or device. This particular configuration allows a user to open the band 12 for placement on the arm and close the band 12 in order to secure the band and body to the arm. The band 12 may be widely varied. By way of example, they may be formed from rubber, silicone, leather, metal, mesh, links and/or the like.

FIG. 2 depicts an example schematic diagram of a wearable electronic device. By way of example, device 100 of FIG. 2 may correspond to the consumer product 10 shown in FIG. 1. To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incor-

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porated into, or performed by device 100, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device 100 may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

As shown in FIG. 2, the device 100 includes one or more processing units 102 that are configured to access a memory 104 having instructions stored thereon. The instructions or computer programs may be configured to perform one or more of the operations or functions described with respect to the device 100. For example, the instructions may be configured to control or coordinate the operation of a display 120, one or more input/output components 106, one or more communication channels 108, one or more sensors 110, a speaker 122, a microphone 124 and/or one or more haptic feedback devices 112.

The processing units 102 of FIG. 2 may be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processing units 102 may include one or more of: a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

The memory 104 can store electronic data that can be used by the device 100. For example, a memory can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing and control signals or data for the various modules, data structures or databases, and so on. The memory 104 can be configured as any type of memory. By way of example only, the memory can be implemented as random access memory, read-only memory, Flash memory, removable memory, or other types of storage elements, or combinations of such devices.

In the schematic diagram of FIG. 2, the one or more input components 106 are represented as a single item within the schematic diagram. However, input components 106 may represent a number of different input components, including buttons, switches, and dials for accepting user input, and so on. More specifically, the input components 106 may correspond to the buttons, dials, crowns or other devices for receiving input. Generally, the input components 106 are configured to translate a user-provided input into a signal or instructions that may be accessed using instructions executed on the processing units 102. In the present example, the input components 106 may include the hardware configured to receive the user input (e.g., button, switch, crown, and encoder) which is operatively coupled to circuitry and firmware used to generate signals or data that are able to be accessed using processor instructions. Each input component 106 may include specialized circuitry for generating signals or data and, additionally or alternatively, circuitry and firmware for generating signals or data may be shared between multiple input components 106. In some cases, the input components 106 produce user-provided feedback for application-specific input that corresponds to a prompt or user interface object presented on display 120. For example, the crown (item 642 of FIG. 6) may be used to receive rotational input from the user, which may be translated into an instruction to scroll a list or object presented on the display 120. The input components 106 may also pro-

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duce user input for system-level operations. For example the input components 106 may be configured to interact directly with hardware or firmware being executed on the device 100 for system-level operations, including, without limitation, power on, power off, sleep, awake, and do-not-disturb operations.

As shown in FIG. 2, the device 100 may also include one or more acoustic elements, including a speaker 122 and a microphone 124. The speaker 122 may include drive electronics or circuitry and may be configured to produce an audible sound or acoustic signal in response to a command or input. Similarly, the microphone 124 may also include drive electronics or circuitry and is configured to receive an audible sound or acoustic signal in response to a command or input. The speaker 122 and the microphone 124 may be acoustically coupled to respective ports or openings in the housing that allow acoustic energy to pass, but may prevent the ingress of liquid and other debris. As shown in FIG. 2, the speaker 122 and microphone 124 are also operatively coupled to the processing units 102, which may control the operation of the speaker 122 and microphone 124. In some cases, the processing units 102 are configured to operate the speaker 122 to produce an acoustic output that corresponds to an application or system-level operation being performed on the device 100. In some cases, the speaker 122 is operatively coupled to other modules, including, for example, input components 106, such as a crown or button. In some implementations, the device 100 is configured to produce an audible output that corresponds to the operation of the crown or buttons using the speaker 122. The microphone 124 may be configured to produce an output or signal in response to an acoustic stimulus. For example, the microphone 124 may be operatively coupled to the memory 104 and may be configured to record audio input, including human speech, music, or other sounds. In some cases, the microphone 124 may be configured to receive voice signals, which may be interpreted as voice commands by the processing units 102.

The one or more communication channels 108 may include one or more wireless interface(s) that are adapted to provide communication between the processing unit(s) 102 and an external device. In general, the one or more communication channels 108 may be configured to transmit and receive data and/or signals that may be interpreted by instructions executed on the processing units 102. In some cases, the external device is part of an external communication network that is configured to exchange data with wireless devices. Generally, the wireless interface may include, without limitation, radio frequency, optical, acoustic, and/or magnetic signals and may be configured to operate over a wireless interface or protocol. Example wireless interfaces include radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces.

In some implementations, the one or more communication channels 108 may include a dedicated wireless communication channel between the device 100 and another user device, such as a mobile phone, tablet, computer, or the like. In some cases, output, including audio sounds or visual display elements, are transmitted directly to the other user device for output to the user. For example, an audible alert or visual warning may be transmitted to a user's mobile phone for output on that device. Similarly, the one or more communications channels 108 may be configured to receive user input provided on another user device. In one example,



the user may control one or more operations on the device 100 using a user interface on an external mobile phone, table, computer, or the like.

Additionally, as described in more detail below with respect to FIG. 17, the communications channels 108 may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce.

As shown in FIG. 2, the device 100 also includes one or more sensors 110 represented as a single item within the schematic diagram. However, the sensors 110 may represent a number of different sensors, including devices and components that are configured to detect environmental conditions and/or other aspects of the operating environment. Example sensors 110 include an ambient light sensor (ALS), proximity sensor, temperature sensor, barometric pressure sensor, moisture sensor, and the like. Thus, the sensors 110 may also be used to compute an ambient temperature, air pressure, and/or water ingress into the device. In some embodiments, the sensors 110 may include one or more motion sensors for detecting movement and acceleration of the device 100. The one or more motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device.

The device 100 also includes one or more biosensors 118 and may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. As described in more detail below with respect to FIG. 16, one or more of the biosensors 118 may include a light source and a photodetector to form a photoplethysmography (PPG) sensor. The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics including, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. One or more of the biosensors 118 may also be configured to perform an electrical measurement using one or more electrodes. The electrical sensor(s) may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, one or more of the biosensors 118 may be configured to measure body temperature, exposure to UV radiation, and other health-related information.

The device 100 may also include one or more haptic devices 112. The haptic device 112 may include one or more of a variety of haptic technologies such as, but not necessarily limited to, rotational haptic devices, linear actuators, piezoelectric devices, vibration elements, and so on. In general, the haptic device 112 may be configured to provide punctuated and distinct feedback to a user of the device. More particularly, the haptic device 112 may be adapted to produce a knock or tap sensation and/or a vibration sensation. As shown in FIG. 2, the haptic device 112 may be operatively coupled to the processing unit 102 and memory 104. In some embodiments, the haptic device 112 may be directly controlled by the processing unit 102. In some embodiments, the haptic device 112 may be controlled, at least in part, by the operation of an input component 106, including, for example, a button, dial, crown, or the like. The operation of the haptic device 112 may also be paired or linked to the operation of one or more other output devices, including, for example, the display 120 or the speaker 122.

As shown in FIG. 2, the device 100 may include a battery 114 that is used to store and provide power to the other components of the device 100. The battery 114 may be a

rechargeable power supply that is configured to provide power to the device 100 while it is being worn by the user. The device 100 may also be configured to recharge the battery 114 using a wireless charging system. Accordingly, in some cases, the device may include a wireless power module 116 that may be configured to receive power from an external device or dock. The wireless power module 116 may be configured to deliver power to components of the device, including the battery 114. The wireless power module 116 and an external charging station or dock may also be configured to transmit data between the device and a base or host device. In some cases, the wireless power module 116 may interface with the wireless charging station or dock to provide an authentication routine that is able to identify specific hardware, firmware, or software on the device in order to facilitate device maintenance or product updates. A more detailed description of an example wireless charging station is provided below with respect to FIGS. 18-19.

The device 100 may include a variety of other components, including for example, a camera or camera modules. The camera may be configured to capture an image of a scene or subject located within a field of view of the camera. The image may be stored in a digital file in accordance with any one of a number of digital formats. In some embodiments, the device 100 includes a camera, which includes an image sensor formed from a charge-coupled device (CCD) and/or a complementary metal-oxide-semiconductor (CMOS) device. The camera may also include one or more optical components disposed relative to the image sensor, including, for example, a lens, an filter, a shutter, and so on.

FIG. 3 depicts functional elements of the device 100, in accordance with some embodiments. In particular, FIG. 3 depicts the inputs that may be received and outputs that may be produced on an example device 100. By way of example, the device 100 may correspond to the devices shown in FIGS. 1 and 2. As shown in FIG. 3, the device 100 may include a force input 302 that may be produced using a force sensor that is configured to detect and measure the magnitude of a force of a touch on a surface of the device. The force input 302 may include a non-binary output that is generated in response to a touch. For example, the force input 302 may include a range of values or analog value that corresponds to the amount of force exerted on a surface of the device. Additionally or alternatively, the force input 302 may include binary (e.g., on, off) output in response to the force of a touch. The force input 302 may be used to control various aspects of the device. For example, the force input 302 may be used to control an aspect, such as a cursor or item selection on a user interface presented on the display of the device. The force input 302 may also be used to control the audio output 308, haptic output 312, and other functionality of the device. The force input 302 may also be used to distinguish between different types of input from the user. For example, a light touch from the user may be interpreted as a scroll command and used to index or scroll through a list of items on the display. A harder touch from the user may be interpreted as a selection or confirmation of an item on the display. In some embodiments, the force input 302 is used to distinguish an intentional touch from the user from an incidental or accidental touch that may be ignored.

As shown in FIG. 3, the device 100 may also include a touch input 306 that may be produced using a touch sensor that is configured to detect and measure the location of a touch on a surface of the device. In some implementations, the touch sensor is a capacitive-based touch sensor that is disposed relative to the display or display stack of the device. The touch sensor may be a separate non-integrated

sensor relative to the force sensor. In alternative embodiments, the touch sensor may also be physically and/or logically integrated with the force sensor to produce a combined output. The touch input 306 may be used to control various aspects of the device. For example, the touch input 306 may be used to control an aspect of the user interface presented on the display of the device. The touch input 306 may also be used to control the audio output 308, haptic output 312, and other functionality of the device.

In some cases, the logical integration of the force input 302 and the touch input 306 enhances the versatility or adaptability of device 100 by enabling a more sophisticated user interface than is currently available on some traditional wearable devices. In particular, the force input 302 and the touch input 306 may be combined to interpret a wider range of gestures and input commands than may be possible using, for example, only a touch input. For example, the force input 302 may provide a magnitude of a force of a touch, which may be used to distinguish between two touch input commands that have a similar location or gesture path. An improved touch interface using both force input 302 and touch input 306 may be particularly advantageous when interpreting touch commands on a relatively small area surface, such as a display screen or cover glass of a wearable electronic device.

As shown in FIG. 3, the device 100 may also include a button/dial input 310 that may be produced using an input device that is configured to receive input from the user. As described previously, the device 100 may include one or more buttons disposed on or near an external surface of the housing and are configured to receive input from a user. The device may also include a dial or crown that is configured to accept rotational input from the user. As described in more detail below with respect to FIGS. 24A-B, the dial or crown may also include a push feature that is adapted to accept input from the user.

The device 100 may also accept audio input 314 using a microphone or other acoustic sensing device. The audio input 314 may be adapted to accept input from the user, including voice commands and other audio signal input. The audio input 314 may also be adapted to detect and measure ambient audio conditions that may be used to adjust the volume of the audio output 308 or operation of the haptic output 312. The audio input 314 may also be used to record an audio stream or voice message in accordance with an audio recording application or software program.

As shown in FIG. 3, the device 100 may include a display output 304 in accordance with some embodiments. The display output 304 includes visual or graphical output that may be produced using the display element of the device. In some embodiments, the display output 304 includes a graphical user interface produced using an operating system or software application executed on one or more processing units of the device. In one example, the display output 304 includes a graphical depiction that resembles a watch face or other timekeeping device. In other examples, the display output 304 includes a graphical interface for an e-mail, text messaging, or other communication-oriented program. The display output 304 may also present visual information that corresponds to one of the other functional aspects of the device 100. For example, the display output 304 may include information that corresponds to the biosensor input 320, sensor input 318, force input 302, touch input 306, and others.

As shown in FIG. 3 the device 100 may include an audio output 308 that may be produced with a speaker or acoustic module. The audio output 308 may include sounds or audio

signals that are associated with the operation of the device. For example, the audio output 308 may correspond to the operation of an input device to provide audio feedback to the user. For example the audio output 308 may correspond to an input received in the form of a force input 302, touch input 306, and/or button/dial input 310. In some cases, the audio output 308 may also include a portion of an auditory alert that may be produced alone or combined with a haptic output 312 and/or display output 304 of the device 100.

The device 100 may also include a sensor input 318 produced using one or more sensors that may be configured to monitor and detect various environmental conditions. For example, the sensor input 318 may include signals or data produced using an ambient light sensor, proximity sensor, temperature sensor, barometric pressure sensor, or other sensor for monitoring environmental conditions surrounding or near the device. In general, the sensor input 318 may be used to adapt the functionality of the device 100 to conform to the one or more environmental conditions. For example, the brightness of the display output 304, the volume of the audio output 308, and/or the operation of the input to the device 100 may be based on the sensor input 318.

In some embodiments, the sensor input 318 includes input produced by one or more motion sensors. The motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device. A sensor input 318 produced using one or more motion sensors may be used to monitor and detect changes in motion of the device 100. Changes in linear and angular motion may be used to determine or estimate an orientation of the device relative to a known location or fixed datum. The sensor input 318 produced from the one or more motion sensors may also be used to track the movement of the user. The movement of the user may be used to facilitate navigation or map-guided functionality of the device. Additionally, input related to the gross movement of the user can be used as a pedometer or activity meter, which may be stored and tracked over time to determine health metrics or other health-related information. Additionally, in some embodiments, sensor input 318 from the one or more motion sensors may be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty).

The device 100 may also include a biosensor input 320 produced using one or more biosensors or biosensor modules that are configured to monitor physiological and/or health conditions of a user. As discussed above with respect to FIG. 2, the device may include one or more optical sensors for measuring heart rate, blood pressure, oxygen saturation, or a combination thereof. The device may also include one or more sensors having electrical contacts that are disposed to contact the user's body. The sensors may be configured to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, sensors may be configured to measure body temperature, exposure to UV radiation, and other health related information. The biosensor input 320 may be combined with other aspects of the device to provide health-monitoring functionality. For example, the biosensor input 320 may be used to compute data that is presented using the display output 304. The operation of the biosensor input 320 may also be controlled using the force input 302, touch input 306, or other user input 310 to provide an interactive health monitoring function or application.



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As shown in FIG. 3, the device may include a haptic output 312 that may be produced using one or more haptic devices that are configured to provide haptic feedback to the user. In particular, the haptic output 312 may be produced using one or more electromechanical subassemblies that are configured to induce motion or vibration in the device, which may be perceived or sensed by the user. In some cases, the haptic actuator or device is tuned to operate based on a resonance or near resonance with respect to the device, which may enhance haptic output. In some cases, the haptic actuator or device is configured to operate based on a resonance or near resonance with respect to some components of the device, such as the band or clasp of the device.

In some embodiments, the haptic output 312 may correspond to the operation of one or more other modules or subsystems. For example, the haptic output 312 may include a vibration or haptic feedback that corresponds to an audio alert or visual alert or signal produced by the acoustic module or display, respectively. Additionally or alternatively, the haptic output 312 may be operated in conjunction with an input from the user. The haptic output 312 may include haptic or force feedback that confirms that the user input was or is being received. By way of example, a haptic output 312 may include a click or vibration when the crown of the device is turned or a button is depressed. The haptic output 312 may also be coordinated with other functionality of the device including, for example, message transmission operations, power management operations, force sensor operations, biosensor operations, to provide a notification, to provide an alert, and others.

As shown in FIG. 3, the device 100 may also include communications input/output (I/O) 316, which may facilitate communication with an external device or system. The communications I/O 316 may be produced using one or more wireless interfaces, including radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. In some cases, the communications I/O 316 may include signals and data received from an external device that has been paired or is otherwise in electronic communication with the device 100. The external data included in the communications I/O 316 may include, for example, message data associated with an electronic communication, notification data associated with an event, and/or data related to audio or visual content. The communications I/O 316 may also include an authorization or identification of external devices in communication with the device 100 or users associated with one or more external devices. Similarly, the communications I/O 316 may be used to output various forms of data or signals to one or more devices or systems that are external to the device 100. For example, the communications I/O 316 may include data or computations that are produced using the biosensor input 320 and/or the sensor input 318.

FIG. 4 depicts an example wearable electronic device 100 as part of a system of devices. By way of example, the wearable electronic device 100 of FIG. 4 may correspond to the devices shown in any of the previous figures. Generally, the wearable electronic device 100 may communicate wirelessly with any of a number of other devices, such as mobile phone 420, computer 430, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Additionally, the wearable electronic device 100 may communicate wirelessly with any of a

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number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. Communication may be through a wired or wireless connection, including any technology mentioned herein.

In some embodiments the wearable electronic device 100 may accept a variety of bands, straps, or other retention mechanisms (collectively, "bands"). These bands may be removably connected to the electronic device by a feature formed into the band or band assembly that is accepted in a recess or other aperture within the device and locks thereto. An example band interface is described in more detail below with respect to FIGS. 25A-C.

In general, a user may change combinations of bands and electronic devices, thereby permitting mixing and matching of the two categories. It should be appreciated that devices having other forms and/or functions may include similar recesses and may releasably mate with a lug and/or band incorporating a lug. In this fashion, a system of bands and devices may be envisioned, each of which is compatible with another. A single band may be used to connect to devices, as one further example; in such embodiments the band may include electrical interconnections that permit the two devices to transmit signals to one another and thereby interact with one another.

Insofar as the electronic device 100 may connect either physically or through a data communication link with other computing devices, the combination of devices and bands may be thought of as an ecosystem having multiple parts that interact with one another, may intelligently communicate with one another, may share functionality and/or may substitute for one another in terms of operations, output, input and the like. Examples of devices existing in such an ecosystem follow, but are illustrative rather than limiting.

As one example, a number of electronic devices 100, 420, 430 may each have identical or similar attachment structures that permit them to share a band or connector. A user may thus change the interconnected band and device(s) with respect to one another, permitting a number of different physical connections between different ecosystem components. In some embodiments, a band that serves to retain an electronic device only may be swapped for bands having additional functionalities, such as transmitting data between devices connected to the band, adding functionality to a connected device that the device lacks, providing additional power to a connected device, and so on. Further, different bands may look different, so that the appearance of the electronic device(s) in combination with a band(s) may change by changing the band(s) and/or device(s) with respect to one another.

As another example, electronic devices 100, 420, 430 may communicate with one another as part of the overall ecosystem. Data may be passed from one device 420 to another 100. This may be useful if the user 410 is wearing one electronic device 100 but is not near another device 430 that wishes to notify the user or interact with the user in some fashion. Continuing the example, the computer 430 may transmit a reminder or message to the wearable device 100 to gain the user's attention. As another example, the computer 430 (or any other electronic device in the ecosystem) may transmit a state of an application or even the device itself to the wearable device 100. Thus, for example, if an application operating on the computer needs the user's attention, it may be gained through an alert issued by the wearable device.

Data communication between devices in an ecosystem may also permit the devices to share functionality. As one

non-limiting example, electronic devices may share sensor data with one another to permit one device access to data it normally would not have, from a sensor it does not physically incorporate. Thus, any given device 100, 420, 430 may draw on the abilities of other devices in the ecosystem to provide an enhanced and relatively seamless experience for a user 410.

FIG. 5 depicts a system 500 of interchangeable components for a wearable device. By way of example, one or more of the devices of FIG. 5 may correspond to the devices shown in any of the previous figures. FIG. 5 depicts a system 500 including a variety of interchangeable components, including multiple device bodies 515, 525, 535 that are configured to connect via a standard interface to any one of a number of different bands 551a-b, 552a-b, 553a-b, 554a-b, and 555a-b. In addition, each of the three devices may be configured to connect via a standard interface to another type of non-band component, such as a lug 556a-b, non-band component, or other device.

As shown in FIG. 5, the system 500 may include a body or device that is adapted to attach to one or more bands, straps, or other similar component that may be used to attach the device to the body of a user. In some embodiments, the device may be interchangeable or interchanged to provide a different set of functions or features. In some embodiments, the bands or attachment components may be interchangeable or interchanged to provide desired functionality or features.

In the example depicted in FIG. 5, each of the devices includes at least one receiving feature 504 that is configured to interconnect with a corresponding feature 502 that is attached to or integrally formed with the end of each of the bands or other mating parts. In some embodiments, receiving feature 504 includes a channel or groove that is formed in one end of the device body. The mating feature 502 of a respective band or component may be configured to slidably engage with the receiving feature 504 of a respective device body to attach the band or component. An example receiving feature is described in more detail below with respect to FIGS. 25A-C. In some embodiments, the receiving feature 504 and the mating feature 502 are standardized in the system 500 and, thus, any of the bands (551a-b, 552a-b, 553a-b, 554a-b, and 555a-b) can be interchangeably used with any of the device bodies 515, 525, 535.

With respect to FIG. 5, each of the bands may be formed from a different material or using a different construction. In the present example, bands 551a-b may be formed from a textile material that may be constructed from a pattern of thread or fiber material. The textile material may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands 552a-b may be formed from a woven material and may be constructed from an array of warp fibers or threads interwoven with one or more weft fibers or threads. Similarly, the warp and weft fibers may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands 553a-b may be formed from leather material 553a-b. In one example, the bands 553a-b are formed from a sheet or strip of cowhide; however, the bands 553a-b may also be formed from one of any number of types of animal hide. The leather material 553a-b may also include a synthetic leather material, such as vinyl or plastic. The bands 554a-b may be formed from a metallic mesh or link construction. For example the bands 554a-b may be formed from a Milanese mesh or other similar type of construction. The bands 555a-b may be formed from a silicone or other elastomer material.

In some cases, the band is a composite construction including various materials, which may be selected based on the end use or application. In some embodiments, a first band strap, or a first portion of the first band strap, may be made up of a first material and a second band strap, or a second portion of the second band strap, may be made from a second, different material. The band may also be made up of a plurality of links and, as such, the band may be resizable by, for example, adding or removing links. Example bands and band constructions are provided below in Section 12.

In the system 500, an interchangeable band may allow for individual customization of the device or to better adapt the device for a range of uses or applications. In some instances, the type of band that is selected and installed can facilitate a particular user activity. For example, band 551a-b may be formed from a textile material and include a durable clasp that may be particularly well suited for exercise or outdoor activities. Alternatively, as discussed above the band 554a-b may be formed from a metallic material and include a thin or low-profile clasp that may be well suited for more formal or fashion-focused activities.

In some embodiments, the band may be coupled to a separate component having the mating feature 502. The band may be coupled using pins, holes, adhesives, screws, and so on. In yet other embodiments, the band may be co-molded or overmolded with at least a portion of the component having the mating feature 502. In some embodiments, the band is coupled to the component via a pin that allows the straps to rotate with respect to the component. The pin may be formed integrally with or disposed in a loop formed in the end of the band.

In the example system 500, each of the bands is shown as having a generic band clasp. However, the type of band clasp that is used may vary between embodiments. On example band clasp may include a first band strap having a buckle or tang assembly which is configured to interface with a second band strap having a series of apertures or holes formed with the strap. Additionally or alternatively, the bands may include a magnetic clasp having one or more magnetic elements on a first band strap that is configured to mate to one or more magnetic or ferromagnetic elements on a second band strap.

As shown in FIG. 5, the system may include multiple device bodies 515, 525, 535 that may vary in size, shape, and composition. The device body 515, 525, 535 may include one or more of the embodiments described herein and may include, but is not limited to a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and/or the like. In particular, the device body may correspond to the device body described with respect to device body 610 of device 100 (shown in FIG. 6).

1. Example Wearable Electronic Device

FIG. 6 depicts an example wearable electronic device, which may include various aspects of the device(s) described above. In some embodiments, multiple modules or subsystems are physically and operationally integrated together to provide particular functionality or device features. In particular, the interaction between the subsystems, or the subsystems themselves, may be configurable by the user, manufacturer, or vendor to adapt the device to produce certain functionality. Some example combinations and interactions between the various modules and subsystems are expressly provided in the present description. However, the combinations and interactions provided herein are merely illustrative in nature and are not intended to be limiting on the scope of the disclosure.



FIG. 6 depicts an example configuration of a wearable electronic device 100. In particular, FIG. 6 depicts an electronic wearable device 100 including a device body 610 that may be configured to be attached to the wrist of a user using a band assembly 620. This configuration may also be referred to herein as a wearable device, a device, an electronic wristwatch, or an electronic watch. While these terms may be used with respect to certain embodiments, the functionality provided by the example electronic wearable device 100 may be substantially greater than or vary with respect to many traditional electronic watches or timekeeping devices.

In the present example, the exterior surface of the device body 610 is defined, in part, by the exterior surface of the housing 601 and the exterior surface of the cover 609. In the example depicted in FIG. 6, the device body 610 is substantially rectangular with round or curved side portions. The outer surfaces of the cover 609 and the housing 601 coincide at a joint interface and cooperate to form a continuous contoured surface. The continuous contoured surface may have a constant radius and may be tangent to a flat middle portion of the cover 609 and/or a flat bottom portion of the housing 601. In some embodiments, the cover 609 has substantially the same shape as a flat bottom portion and at least a portion of the curved side portions of the housing 601. A more complete description of the geometry of the cover 609 and the housing 601 is provided below with respect to FIGS. 7 and 8.

In the example of FIG. 6, the device 100 includes a display (item 120 of FIG. 2) that is disposed at least partially within an opening or cavity defined within a top portion of the housing 601 of the device body 610. The display may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user and may be operated in accordance with one or more display modes or the software applications being executed on the device 100. By way of example, the display may be configured to present the current time and date similar to a traditional watch or timepiece. The display may also present a variety of other visual information that may correspond to or be produced using one of the other modules in the device 100. For example, the display may be configured to display one of a variety of notification messages, which may be generated based on data received from the one or more sensors, the wireless communication system, or other subsystem of the device 100. The display may also be configured to present visual information or data that is based on the output of one or more sensor outputs. The display may also provide status or information related to a wireless charging process or battery power. The display may also present visual output or information related to media being produced using a speaker or acoustic module of the device 100. Accordingly, a variety of other types of visual output or information may be presented using the display.

In the current example, the display includes or is integrated with a cover 609 that helps to protect the display from physical impact or scratches. In the field of wearable devices, the cover 609 may also be referred to generically as a crystal or cover glass, regardless of the material that is used to form the cover 609. In some cases, the cover 609 is formed from a sheet or block of sapphire material. Sapphire may provide superior optical and surface hardness properties as compared to other materials. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. In alternative embodiments, the cover 609 is formed

from a glass, polycarbonate, or other optically transparent material. The cover 609 may also be coated with one or more optical or mechanical enhancing materials or surface treatments. For example, interior and/or exterior surfaces of the cover 609 may be coated with an anti-reflective (AR), oleophobic or other coating to enhance the visible or functional properties of the display. Additionally, in some cases, the cover 609 may be configured to cooperate with an antenna used to facilitate wireless communication with an external device. FIGS. 21A-B, described in more detail below, provide one example embodiment of a cover configured to cooperate with an antenna.

In the example depicted in FIG. 6, the cover 609 is formed from a transparent material and, when assembled has an external surface and an internal surface. The cover 609 is disposed above the display and encloses a cavity or opening formed in the top portion of the housing 601. In some embodiments, the external surface of the cover 609 cooperates with the external surface of the housing to form a substantially continuous external peripheral surface of the electronic device. As shown in FIG. 6, the external surface of the cover 609 has a flat middle portion at the center of the cover, which extends outwardly. The cover 609 also includes a curved edge portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge at the side of the cover 609. In some embodiments, the cover 609 also includes an opaque mask disposed relative to the internal surface of the transparent cover. The opaque mask may correspond to or otherwise define the viewable area of the display 120. The mask may have an outer boundary that is located proximate the edge of the side of the cover 609 and has an inner boundary located within the curved edge portion of the cover 609.

As shown in FIG. 6, the cover 609 is disposed relative to a top portion of the housing 601. The housing 601 includes a top portion defining an opening, which is surrounded by a curved side portion. In the present example, the curved edge portion of the cover 609 coincides with the curved side portion of the housing 601 to form a continuous external surface of the electronic device 100. In some instances, the cover 609 may have a contour that follows or otherwise corresponds to a similar contour of the housing 601 to form a substantially continuous surface at the interface between the two components. As shown in FIG. 6, the cover 609 protrudes above the housing 601.

In some instances, the cover 609 is disposed relative to a touch sensor (item 702 of FIG. 7). In some embodiments, the touch sensor may be integrated with the display or other element of the device 100. The touch sensor may be formed from one or more capacitive sensor electrodes or nodes that are configured to detect the presence and/or location of an object or the user's finger that is touching or nearly touching the surface of the display. In some cases, the touch sensor includes an array of sensing nodes formed in accordance with a mutual capacitance sensing scheme.

In one example, the touch sensor may include an array of mutual capacitance touch nodes that can be formed by a two-layer electrode structure separated by a dielectric material. One layer of electrodes may comprise a plurality of drive lines and another layer of electrodes may comprise a plurality of sense lines, and where the drive lines and the sense lines cross, mutual capacitive sense nodes are formed (also referred to as coupling capacitance). In some implementations, the drive lines and sense lines may cross over each other in different planes separated from one another by a dielectric. Alternatively, in other embodiments the drive lines and sense lines can be formed substantially on a single

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layer. An example touch sensor and touch-sensing node are described in more detail below with respect to FIGS. 14A-C and 15A-B.

Alternatively or additionally, the touch sensor may include one or more self-capacitive nodes or electrodes that are configured to detect a discharge of electrical current or charge when an object, such as a user's finger, contacts or nearly contacts a surface of the housing 601 or other surface of the device 100. Other types of electronically sensing nodes, including resistive, inductive, or the like, may also be integrated into a surface of the device 100.

In some embodiments, the device 100 may also include a force sensor (item 705 of FIG. 7). The force sensor may be disposed relative to the display 120 or integrated with other elements of the device 100. In some cases, the force sensor includes one or more force sensing structures or force-sensing nodes for detecting and measuring the magnitude of a force or pressure due to a touch on a surface of the device 100. The force sensor may be formed from or implement one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a force or pressure due to a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on the deflection. Example force sensor and force-sensing modules are described in more detail below with respect to FIGS. 9-12.

As shown in FIG. 6, the device 100 also includes device body 610 including a housing 601 that upon which may be mounted or integrated with various components of the device 100. The housing 601 serves to surround at a peripheral region as well as support the internal components of the product in their assembled position. In some embodiments, the housing 601 may enclose and support internally various components (including for example integrated circuit chips and other circuitry) to provide computing and functional operations for the device 100. The housing 601 may also help define the shape or form of the device. That is, the contour of the housing 601 may embody the outward physical appearance of the device. As such, it may include various ornamental and mechanical features that improve the aesthetical appearance and tactile feel of the device. For example, the housing 601 may include a contoured surface that includes rectilinear contours, curvilinear contours, or combinations thereof. The housing 601 may also include various surface features, including textures, patterns, decorative elements, and so on.

In the present example, the housing 601 is formed from a single piece, which may also be referred to as single-body, unitary, or uni-body design or construction. By utilizing a single-body construction, the structural integrity of the device may be improved as compared to a multi-piece construction. For example, a single body may be more easily sealed from contaminants as compared to a multi-piece enclosure. Additionally, a single-body enclosure may be more rigid due, in part, to the absence of joints or seams. The rigidity of the housing 601 may be further enhanced by increasing the material thickness in areas where mechanical stress may be greatest, while also maintaining or thinning other areas where mechanical stress may be lower or reduced. Variations in the thickness of the housing 601 may be possible by machining or casting the housing 601 as a single piece. Additionally, a single-body housing 601 may include one or more features for mounting or integrating the

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internal components of the device 100, which may facilitate manufacturing and/or assembly of the device 100.

An example housing 601 is described in more detail below with respect to FIG. 8. The housing 601 may be formed from a variety of materials, including, without limitation plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, magnesium), other suitable materials, or a combination of these materials. Further, the housing 601 may include a surface treatment or coating, which may be formed from a variety of materials, including, without limitation aluminum, steel, gold, silver and other metals, metal alloys, ceramics, wood, plastics, glasses, and the like.

As discussed above, the display, the touch sensor, and force sensor may be disposed within the housing 601. In this example, one or more buttons 644 and a crown 642 used to receive user input may also be disposed within or relative to the housing 601. Other types of user input, including for example, one or more dials, slides, or similar user input devices or mechanisms may also be disposed within or relative to the housing 601. As described in more detail with respect to FIGS. 7 and 8, the housing 601 may include various features for attaching and mounting the subassemblies and modules of the device 100. In particular, the housing 601 may have one or more openings for receiving the cover 609, the display, the force sensor, or other components. The housing 601 may also include one or more holes or openings for receiving the button 644 and crown 642 that are located around the perimeter of the device 100. In some embodiments, the housing 601 also includes internal features, such as bosses and threaded portions, that can be used to attach modules or components within the housing 601.

The device 100 may also include an ambient light sensor (ALS) that is configured to detect and measure changes in ambient lighting conditions. The ALS may include a photodiode and one or more optical elements or lenses for collecting light. An ALS may be located on an external facing surface that is less likely to be blocked when the device is worn or in use. The ALS may be used to adjust settings, including screen brightness and other visual output depending on the overall lighting conditions.

The housing 601 may also include one or more motion-sensing elements or devices for detecting motion of the device 100. For example, the device 100 may include one or more accelerometers that are configured to sense acceleration or changes in motion. Additionally or alternatively, the device 100 may include one or more gyroscopic sensors that are configured to detect changes in direction. In some cases, the one or more gyroscopic sensors may include a spinning mass that can be used to detect changes in angular velocity. Multiple motion-sensing elements may be used to detect motion along multiple directions or axes. The motion sensors may also be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty). The one or more motion-sensing elements may be used to determine an orientation of the device relative to a known or fixed datum. For example, the device may include a compass and/or global positioning system (GPS) that can be used to identify an absolute position. The one or more motion sensing elements may then measure deviation or movement with respect to the absolute position to track movement of the device or the user wearing the device. In some implementations, the one or more motion-sensing elements are used to detect gross movement of the device or user. The gross movement may be used as



a pedometer or activity meter, which may be tracked over time and used to calculate a health metric or other health-related information.

Described in more detail with respect to FIG. 8, the housing 601 may also include one or more openings or orifices coupled to an acoustic module or speaker 122, which may include a speaker and/or a microphone subassembly. Although the housing 601 may include one or more openings or orifices, the housing 601 may still be substantially waterproof/water resistant and may be substantially impermeable to liquids. For example, the opening or orifice in the housing or enclosure may include a membrane or mesh that is substantially impermeable to liquid ingress. Additionally or alternatively, the geometry of the opening or orifice and other internal features of the housing 601 may be configured to reduce or impede the ingress of liquid or moisture into the device 100. In one example, the opening is formed from one or more orifices that are offset with respect to an internal acoustic chamber or cavity, which may prevent a direct path from the outside of the housing 601 into the acoustic module.

As shown in FIG. 6, the device 100 includes a device body 610 that may be attached to a user's wrist using a band 620. In the present example, the band 620 include a first band strap 621 attached to a first receiving feature 623 and a second band strap 622 attached to a second receiving feature 624. In some embodiments, the first and second band straps 621, 622 include a lug feature that is configured to attach to the first and second receiving features 623, 624, respectively. As shown in FIG. 6, the free ends of the band straps 621, 622 are connected with a clasp 625.

The band straps 621, 622 are formed from a flexible or compliant material that may be specially configured for a particular application. The band straps 621, 622 may be formed from a variety of materials, including, for example, leather, woven textiles, or metallic mesh materials. The material and construction of the band straps 621, 622 may depend on the application. For example, the band straps 621, 622 may be formed from a woven textile material configured for exposure to impact and moisture typically associated with outdoor activities. In another example, the band straps 621, 622 may be formed from a metallic mesh material that may be configured to have a fine finish and construction that may be more appropriate for professional or social activities.

Similarly, the clasp 625 of the band 620 may be configured for a particular application or to work with a particular style of band. For example, if the band straps 621, 622 are formed from a metallic mesh material, the clasp 625 may include a magnetic clasp mechanism. In the present example, the device 100 is configured to be attached to the wrist of a user. However, in alternative embodiments, the device may be configured to be attached to the arm, leg or other body part of the user.

The housing 601 includes one or more features for attaching the band straps 621, 622. In the present example, the housing 601 includes a first receiving feature 623 and a second receiving feature 624 for attaching the first band strap 621 and the second band strap 622, respectively. In this example, the band straps 621, 622 include a lug portion that is adapted to mechanically engage with the receiving features 623, 624. A more detailed description of the receiving features and lugs is provided below with respect to FIGS. 25A-C. As shown in FIG. 6, the first 623 and second receiving features 624 may be integrally formed into the housing 601. In alternative embodiments, the receiving features may be formed from separate parts and may be attached to the housing 601 during manufacturing. In some

embodiments, the receiving features 623, 624 may be configured to release the band straps 621, 622 from the device body 610 (e.g., the housing 601). For example, one or both of the receiving features 623, 624 may include a button or slide, which may be actuated by the user to release a corresponding band strap 621 and 622. One advantage of a releasable lug is that the user can swap between a variety of bands that may be specially configured for a particular use scenario. For example, some bands may be specially configured for sport or athletic activities and other bands may be configured for more formal or professional activities.

The device 100 may also include a rear cover 608 located on the rear-facing surface of the housing 601 of the device body 610. The rear cover 608 may improve the strength and/or scratch resistance of the surface of the device 100. For example, in some embodiments, the rear cover 608 may be formed from a sapphire sheet, zirconia, or alumina material having superior scratch resistance and surface finish qualities. In some cases, the sapphire material has a hardness greater than 6 on the Mohs scale. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. Due to the superior strength of the sapphire material, a cover glass formed from a sapphire sheet may be very thin. For example, the thickness of a sapphire cover sheet may be less than 300 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 100 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 50 microns thick. In some embodiments, the rear cover 608 is contoured in shape. For example, the rear cover 608 may have a convex curved surface.

FIG. 7 depicts an example exploded view of various modules and subassemblies of the device 100. As shown in FIG. 7, multiple components are configured to be disposed within and/or attached to the housing 601. The exploded view provided in FIG. 7 depicts one example arrangement of the components of the device 100. However, in other embodiments, arrangement, placement, and/or grouping of the subassemblies and the components of the subassemblies may vary.

In the present example, a main cavity of the housing 601 houses an electronics subassembly 720 and the battery 114 of the device. The electronics subassembly 720 includes one or more electrical circuit assemblies for coupling the various electrical components of the device 100 to each other and to power supplied by the battery 114. The electronics subassembly 720 may also include structural elements or components that provide structural rigidity for the electronics subassembly 720 and/or structural mounting or support for other components disposed within the housing 601. As shown in FIG. 7, within the cavity of the housing 601, the speaker 122, the crown module 642, and the battery 114 are all disposed above the electronics subassembly 720. In the present embodiment the top surface of the speaker 122, the crown module 642, and the battery 114 have a substantially similar height. In some embodiments, the speaker 122, the crown module 642, and the battery 114, when assembled in the housing 601, define an area for the display 120 within the cavity. Thus, as shown in FIG. 7, the display 120 may overlay the speaker 122, the crown module 642, and the battery 114, which overlay the electronics subassembly 720.

As shown in FIG. 7, the cover 609 is configured to fit within a corresponding recess formed within the housing 601. In particular, the cover 609 includes a vertical portion having a height that corresponds to the depth of the recess formed within the housing 601. In this example, the device 100 includes a force sensor 705 disposed between the housing 601 and a cover subassembly 704. As described in

more detail below with respect to FIGS. 9 and 10A-B, the force sensor 705 may be configured to detect a force placed on a surface of the cover 609 by detecting a relative deflection between the cover 609 (or cover subassembly 704) and the housing 601. In the present example, the force sensor 705 also forms a gasket or seal between the cover subassembly 704 and the housing 601. In some implementations, the seal is a water-proof or water-resistant seal that helps to prevent water or liquid ingress into the internal cavity of the housing 601. The force sensor 705 may also be used to join the cover subassembly 704 to the housing 601 using an adhesive or film.

In some embodiments, the cover subassembly 704 includes the cover 609 which is disposed above the touch sensor 702 and display 120. In the present example, the touch sensor 702 and the display 120 are attached to each other by an optically clear adhesive layer (OCA). Similarly, an OCA layer is used to attach the touch sensor 702 to the cover 609. Other adhesives or bonding techniques may be used to attach the display 120 and the touch sensor 702 to the cover 609. In some embodiments, the touch sensor 702 is integrated into the display 120 and the display 120 (and integrated touch sensor 702) are attached to the cover 609.

As shown in FIG. 7, the speaker 122 is also disposed within the cavity of the housing 601. The speaker 122 is adapted to mechanically and acoustically interface with a port formed in the side of the housing 601. In some embodiments, the port is configured to prevent a direct path for water or liquid into an acoustic chamber or cavity of the speaker 122. In some embodiments, the device 100 also includes a microphone that is similarly coupled to another port formed in the side of the housing 601. A more detailed description of the speaker 122 and microphone is provided below with respect to the acoustic module of FIG. 20.

In the present example, the haptic device 112 is also disposed within the cavity of the housing 601 proximate to the speaker 122. In some embodiments, the haptic device 112 is rigidly mounted to a portion of the housing 601. A rigid mounting between the housing 601 and the haptic device 112 may facilitate the transmission of vibrations or other energy produced by the haptic device 112 to the user. In the present example, the haptic device 112 includes a moving mass that is configured to oscillate or translate in a direction that is substantially parallel with a rear face of the housing 601. In some implementations, this orientation facilitates the perception of a haptic output produced by the haptic device 112 by a user wearing the device 100. While this configuration is provided as one example, in other implementations, the haptic device 112 may be placed in a different orientation or may be configured to produce a haptic response using a rotating mass or other type of moving mass.

As shown in FIG. 7, the device also includes an antenna subassembly 722. In this example, a portion of the antenna subassembly 722 is disposed within the housing 601 and a portion of the antenna subassembly 722 is disposed within the cover assembly. In some implementations, a portion of the antenna subassembly 722 is disposed relative to a feature formed within the cover 609. An example embodiment is described in more detail below with respect to FIGS. 21A-B.

In the example depicted in FIG. 7, the device 100 also includes a crown module 642 which is disposed in an aperture or hole in the housing 601. When installed, a portion of the crown module 642 is located outside of the housing 601 and a portion of the crown module 642 is disposed within the housing 601. The crown module 642 may be configured to mechanically and/or electrically coop-

erate with the electronics subassembly 720. A more detailed description of an example crown module is provided below with respect to FIGS. 23 and 24A-B. The housing 601 also includes a button 644, which is disposed in an opening of the housing 601 and may be configured to mechanically and/or electrically cooperate with the electronics subassembly 720.

In the example depicted in FIG. 7, a biosensor module 710 is disposed in an opening formed in the rear surface of the housing 601. In some embodiments, the biosensor module 710 includes the rear cover 608 and may also include a chassis or plate that facilitates attachment of the biosensor module 710 to the housing 601. The chassis or plate or the cover sheet 608 may also include features or elements that facilitate a watertight seal between the biosensor module 710 and the housing 601. For example, the rear cover 608 may include a shelf or flange that may be used to form a seal between the biosensor module 710 and the housing 601. As described in more detail below with respect to FIG. 16, the biosensor module 710 may include one or more light sources, one or more photodetectors, and one or more electrodes or conductive elements that are configured to detect and measure a physiological condition or property of the user.

In some embodiments, the rear cover 608 has an edge that protrudes outwardly from the back surface of the housing 601. The rear cover 608 may also have a convex curved area located between the edges of the rear cover 608. The convex curved area of the rear cover 608 may include one or more windows or apertures that provide operational access to one or more internal components located within the housing 601. In some embodiments, the windows have a curvature that matches the curvature of the convex curved area of the rear cover.

2. Example Housing

As described above, a wearable electronic device may include a device body that includes a housing or enclosure shell. As previously described, the housing may function as a chassis that physically integrates the various components of the device. The housing may also form a protective shell or housing for the components and function as a barrier against moisture or debris. In the present examples, the housing is formed as a uni-body, unitary, or single body or component. A single-body construction may be advantageous by providing mounting features directly into the housing, which may reduce space, reduce part count, and increase structural rigidity as compared to some alternative configurations. Additionally, a single-body construction may improve the housing's ability to prevent the ingress of moisture or debris by reducing or eliminating seams or joints between external components.

FIG. 8 depicts an example housing 601 in accordance with some embodiments. In the present example, the housing 601 is formed as a single body or component. As shown in FIG. 8, the housing 601 is formed as a single part or body. The housing 601 may be formed, for example, by machining or shaping a solid or cast blank having the approximate shape of the housing 601. In some implementations, the housing 601 may be configured to provide structural integrity for potentially delicate internal components and also withstand a reasonable impact.

In the present embodiment, the housing 601 is formed as a uni-body, unitary, or single-body construction having a flat bottom portion 801 and a top portion including flange 812. The top portion defines an internal cavity 805, which is surrounded by four sides 802a-d that are integrally formed with the bottom portion 801. The internal cavity 805 can also be described as being defined by the top portion, the four



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sides 802a-d and the bottom portion 801. In this example, the internal cavity 805 has a rectangular (square) shape, although the specific shape may vary with different implementations. In the present example, the four sides 802a-d define a curved side portion of the housing 601 that extends from the bottom portion 801 to the top portion of the housing 601. Each side 802a-d is orthogonal to an adjacent side and each side 802a-d is connected to an adjacent side by a rounded corner. For example, side 802a is orthogonal to two adjacent sides 802b and 802d and is connected to those sides by respective rounded corners. The shape or contour of the rounded corners may correspond to the curvature of the curved portion of the housing 601. Specifically, the curvature of the rounded corners may match or correspond to the curvature of the continuous external surface formed by the housing 601 and the cover 609, as described above with respect to FIG. 6.

The sides 802a-d may vary in thickness in order to provide the structural rigidity for the device. In general, areas of high stress may have an increased material thickness as compared to areas of low stress, which may have a reduced material thickness. In particular, portions of the sides 802a-d near the bottom portion 801 may have an increased thickness as compared to portions of the sides 802a-d located further away from the bottom portion 801. This configuration may improve the structural rigidity and overall stiffness of the housing 601.

As shown in FIG. 8, one or more mounting features may be formed directly into the housing 601, which may reduce the number of parts and also enhance the structural integrity of the device. As shown in FIG. 8, receiving features 623, 624 may be formed as channels or openings that are configured to receive an end of a band (e.g., a lug) having a mating feature. As described above with respect to FIG. 5, the receiving features 623, 624 may be standardized and configured to work with a system of interchangeable components. Forming the receiving features 623, 624 directly into the housing 601 may reduce parts and also facilitate structural rigidity of the device.

In the example depicted in FIG. 8, the housing 601 can be described as having two ends (a first end and a second end opposite the first end), and a first side and a second side opposite the first side, the sides being continuous with the ends. In this example, the first and second ends and the first and second sides having an outwardly curved three-dimensional shape. In this example, the receiving feature 623 is formed from a first groove situated in the first end. Similarly, the receiving feature 624 is formed from a second groove situated in the second end. In the present example the grooves have openings at the interface of the first and second sides and first and second ends. As shown in FIG. 8 the groove also has an inwardly curved concave three-dimensional shape with an undercut feature. For example, the middle portion of the groove of receiving features 623, 624 may have a width that is greater than the opening of the receiving features 623, 624. In some embodiments, the upper portion of the housing overhangs the lower portion of the housing at the groove opening. In the example depicted in FIG. 8, the groove is cut into a solid portion of the housing such that the groove forms a continuous interior shape.

The geometry of the receiving features may be located with respect to other features or components of the device. In the example depicted in FIG. 8, at least a portion of the groove of the receiving features 623, 624 may be disposed underneath the cover (item 609 of FIGS. 6-7). With respect to FIG. 6, the groove of the receiving features 623, 624 is located underneath the opening for the cover, which is

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defined by the sealing ledge 810 and flange 812 formed in the upper portion of the housing 601. In some embodiments, the length of the groove extends further than the width of the opening configured to receive the cover (and thus the cover, when assembled). In some embodiments, the grooves are formed at an angle relative to the centerline of the housing. In some cases, the angle is approximately 5 degrees. In some embodiments, the groove is located underneath the centerline of the housing 601. In some embodiments, the groove is angled upward toward the top of the housing 601 and inward toward the center of the housing 601. The groove may angle upward and cross the centerline of the housing. In some cases, the groove crosses the vertical centerline of the housing 601.

In the present embodiment, the housing 601 also includes an aperture 821 formed into the side 802c of the housing 601 for attaching a crown or crown module (item 642 of FIGS. 6-7). In some embodiments, the aperture 821 for the crown is offset upwardly from the centerline of the housing 601. In some embodiments, the aperture 821 for the crown is positioned such that an upper portion of a crown (when installed) is higher than the interface of cover 609 and housing 601. With respect to FIG. 6, the interface may correspond to the upper edge of the flange 812.

The housing 601 also includes an opening 822 formed into the side 802c of the housing 601 for attaching the button (item 644 of FIGS. 6-7). In some embodiments, the aperture 821 for the crown and the opening 822 for the button are disposed with the length defined by a flat part of the cover. In some embodiments, the aperture 821 for the crown is disposed above the centerline of the housing 601 and the opening 822 for the button is disposed below the centerline of the housing 601. In some embodiments, the aperture 821 for the crown and the opening 822 for the button are disposed on a curved surface of the housing 601. The housing 601 may also include various other internal features, including threaded features and bosses, for attaching other internal components of the device.

In some cases, the housing 601 may be formed as a single-piece or integral enclosure shell to enhance the structural rigidity and/or liquid-sealing properties of the device. As described above with respect to FIGS. 6 and 7, the housing 601 may be integrated with a cover (e.g., crystal) and other external components to provide a substantially sealed housing. In the present embodiment, the housing 601, includes a sealing ledge 810 formed around the perimeter of the main cavity 805 formed within the housing 601. In some embodiments, the sealing ledge 810 (and thus the cover when installed) is located in the center of the housing 601. The sealing ledge 810 may be defined by a substantially flat portion 811 that is adapted to form a seal between the housing 601 and another component (e.g., the force sensor 705 or cover 609 of FIGS. 6-7). The sealing ledge 810 may be formed at a depth that is substantially similar or corresponds to the thickness of the mating cover.

As shown in FIG. 8, the sealing ledge 810 may also include flange 812 that protrudes from the flat portion and forms a continuous surface with the side walls 802a-d. In some cases, the flange 812 is configured to cooperate with the cover (item 609 of FIGS. 6-7) to form a substantially continuous surface. In some implementations, the sides 802a-d and the cover or crystal are configured to cooperate or mechanically interface to improve the strength and the water sealing properties of the device.

As also shown in FIG. 8, an opening or aperture 815 may be formed in the bottom portion 801 of the housing 601. In some embodiments, the opening or aperture 815 is located

at the center of the housing 601. As described above with respect to FIG. 7, the aperture 815 may be used to integrate a sensor array or other module used to collect measurements that may be used to compute a health metric or other health-related information. The present embodiment may be advantageous by integrating multiple components in a single opening 815, which may facilitate a water-proof or water-resistant property of the device. Additionally, by integrating a sensor array into a module that attaches via the opening 815, same housing 601 may be used with a variety of sensing configurations or arrays. For example, the number or sensors or components may be increased or decreased without modifying the housing 601. This may allow for flexibility in the product development and may facilitate upgrades as new sensing configurations are available.

As previously discussed above with respect to FIGS. 6-7, the housing 601 may also be configured to serve as a protective housing for one or more acoustic elements, such as a microphone or speaker. Additionally, in some embodiments, the housing 601 may also be configured to inhibit the ingress of foreign particulate or moisture. In particular, the housing 601 may include a speaker port having orifices 831, 832 that are configured to transmit acoustic signals but also prevent the ingress of liquid or other foreign particulate. In the present example, the speaker port includes orifices 831, 832 that are offset with respect to an acoustic chamber or cavity to prevent the direct ingress of liquid into the speaker subassembly or acoustic module. In the present example, a shielding or umbrella portion of the housing, which is substantially free of openings, is formed between the orifices 831, 832, which helps to prevent the direct ingress of liquid. Similarly, the housing 601 includes a microphone port having orifices 833, 834 that are offset from a corresponding acoustic chamber or cavity to prevent the direct ingress of liquid into the microphone subassembly or acoustic module.

In the example depicted in FIG. 8, the orifices 831, 832 of the speaker port are located on one side of the aperture 821 for the crown and the orifices 833, 834 for the microphone are located on the other side of the aperture 821. Both the orifices 831, 832 of the speaker port and the orifices 833, 834 for the microphone are located on a curved portion of the housing 601.

3. Example Force Sensor and Touch Sensor

As discussed previously, a wearable electronic device may include one or more sensors for detecting the location and force of a touch. For the purposes of the following description of the force sensor and touch sensor, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100 including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a force sensor and a touch sensor may be disposed relative to the display of a wearable electronic device for to form a touch-sensitive surface. The following description is provided with respect to individual force and touch sensors that may be used to determine the force and location of a touch, respectively. However, in some embodiments, a single integrated sensor may be used to detect both the force and location of a touch on the device.

In one embodiment, an output from a force sensor may be combined with a touch sensor to provide both location and force of a single touch or of multiple touches on the surface of a device. In an alternative embodiment, a hybrid or integrated force and touch sensor may be used to sense both touch force and location of a single touch or of multiple touches. In either embodiment, by sensing both the force and

location of a touch, multiple types of user input may be generated and interpreted. In one example, a first touch may be correlated with a first force and a first touch location or gesture. Based on the magnitude of the force, the first touch may be interpreted as a first type of input or command. A second touch may be sensed as having a second, different force and a similar location or gesture as the first touch. Based in part on the magnitude of the second force, the second touch may be interpreted as a second type of input or command. Thus, a force sensor (alone or in combination with another touch sensor) may be used to produce different responses or outputs depending on the force of the touch.

The one or more force sensors may be formed from or may be implemented as one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on a deflection of the surface, such as the cover glass.

By way of example, the force sensor may include a capacitive force sensor, which may be formed from one or more capacitive plates or conductive electrodes that are separated by a compressible element or other compliant member. As a force is applied to a surface of the device, the compressible element may deflect resulting in a predictable change in the capacitance between the plates or electrodes. In some implementations, a capacitive force sensor may be formed from transparent materials and disposed over the display. In other implementations, a capacitive force sensor may be formed from non-transparent materials and disposed beneath or around the perimeter of a display.

FIG. 9 depicts a detail cross-sectional view of a portion of a force sensor 900 that may be arranged around the perimeter of a display 120. As shown in FIG. 9, a force-sensing structure 901 of the force sensor 900 may be disposed beneath the cover 609 and along the side of an edge or the perimeter of the display 120. In this example, the force sensor 900 is configured to detect and measure the force of a touch on the surface 911 of the cover 609. In the present embodiment, a first capacitive plate 902 is fixed with respect to the cover 609. A second, lower capacitive plate 904 is fixed with respect to the housing 601 and may be disposed on a shelf or mounting surface located along the perimeter of the device. The first capacitive plate 902 and the second capacitive plate 904 are separated by a compressible element 906.

In the configuration depicted in FIG. 9, a touch on the surface 911 of the device may cause a force to be transmitted through the cover 609 of the device and to the force sensor 900. In some cases, the force causes the compressible element 906 to compress, thereby bringing the first capacitive plate 902 and the second capacitive plate 904 closer together. The change in distance between the first and second capacitive plates 902, 904 may result in a change of capacitance, which may be detected and measured. For example, in some cases, a force-sensing circuit may measure this change in capacitance and output a signal that corresponds to the measurement. A processor, integrated circuit or other electronic element may correlate the circuit output to an estimate of the force of the touch. Although the term "plate" may be used to describe certain elements, such as the capacitive plates or conductive electrodes, it should be



appreciated that the elements need not be rigid but may instead be flexible (as in the case of a trace or flex).

FIG. 10A depicts an example configuration of the force sensor 1000 having four individual force-sensing structures 1001a-d arranged around the perimeter of a display in a device. For the sake of clarity, the crystal, display, and other elements of the device are omitted from the depiction of FIG. 10A. Each of the force-sensing structures 1001a-d may be formed from a pair of capacitive plates separated by a compressible element. Additionally, each force-sensing structure 1001a-d may be separated by a small gap at or near the corners of the opening in the housing 601. In the example depicted in FIG. 10A, the four individual force-sensing structures 1001a-d may each be operatively coupled to force-sensing circuitry that is configured to detect a change in the capacitance of each force-sensing structure 1001a-d. Using the example arrangement depicted in FIG. 10A, the approximate location of the touch may be determined by comparing the relative change in capacitance of each force-sensing structure 1001a-d. For example, a change in capacitance of structure 1001b that is larger as compared to a change in capacitance of structure 1001d may indicate that the touch is closer to structure 1001b. In some embodiments, the degree of the difference in the change in capacitance may be used to provide a more accurate location estimate.

While the configuration shown in FIG. 10A depicts the force-sensing structures as individual elements separated by a small gap, in some embodiments, the force-sensing structure may be formed as a single continuous piece. FIG. 10B depicts a force sensor 1050 formed as a single force-sensing structure 1051 formed as a continuous part along the perimeter of the display. Similar to the example described above, the force-sensing structure 1051 may be operatively coupled to force sensing circuitry that is configured to detect a change in the capacitance of one or more capacitive elements of the force-sensing structure 1051. While the force-sensing structure 1051 is formed as a continuous structure, there may be multiple sensing elements (e.g., capacitive plates) that are disposed within the structure at different locations, and which may be configured to detect deflection or compression of the structure over a portion of entire area of the force-sensing structure 1051. In some embodiments, the force-sensing structure 1051 may also function as a seal or gasket to prevent ingress of moisture or other foreign contaminants into the main cavity of the housing. Additionally, the force-sensing structure 1051 may be integrated with one or more sealing or adhesive layers that also function as a barrier for foreign contaminants.

As mentioned previously, the force sensor may additionally or alternatively include a strain-based sensing configuration. The strain-based sensing configuration may include, for example, a charge-based or resistive sensor configuration. FIG. 11 depicts a cross-sectional view of a device having an example force sensor 1100 that uses one or more force-sensitive films to detect and measure the force of a touch on a surface 1111 of the cover 609. In this example, the force sensitive film 1102 and 1104 are formed from a transparent material and are disposed relative to a viewable portion of the display 120. As shown in FIG. 11, the force sensor 1100 includes a first force-sensitive film 1102 and a second force-sensitive film 1104 that are separated by one or more intermediate layers 1106. The force-sensitive films 1102, 1104 may be configured to produce different electrical outputs in response to a strain or deflection of the cover 609. In some cases, the intermediate layer 1106 is compressible to allow the first force-sensitive film 1102 to deflect with respect to the second force-sensitive film 1104. In other

cases, the intermediate layer 1106 may not be compressible and the first force-sensitive film 1102 deflects in a predictable manner with respect to the second force-sensitive film 1104. While FIG. 11 depicts an example force sensor 1100 having two force-sensitive films, alternative embodiments may include only a single force-sensitive film or, alternatively, include more than two force-sensitive films.

In general, a transparent force-sensitive film may include a compliant material that exhibits an electrical property that is variable in response to deformation or deflection of the film. The transparent force-sensitive film may be formed from a piezoelectric, piezo-resistive, resistive, or other strain-sensitive materials. Transparent resistive films can be formed by coating a substrate with a transparent conductive material. Potential transparent conductive materials include, for example, polyethyleneioxythiophene (PEDOT), indium tin oxide (ITO), carbon nanotubes, graphene, silver nanowire, other metallic nanowires, and the like. Potential substrate materials include, for example, glass or transparent polymers like polyethylene terephthalate (PET) or cycloolefin polymer (COP). Typically, when a piezo-resistive or resistive film is strained, the resistance of the film changes as a function of the strain. The resistance can be measured with an electrical circuit. In this way, a transparent piezo-resistive or resistive film can be used in a similar fashion as a strain gauge.

If transparency is not required, then other film materials may be used, including, for example, Constantan and Karma alloys for the conductive film and a polyimide may be used as a substrate. Nontransparent applications include force sensing on track pads or the back of display elements. In general, transparent and non-transparent force-sensitive films may be referred to herein as "force-sensitive films" or simply "films."

In some embodiments, the force-sensitive film is patterned into an array of lines, pixels, or other geometric elements herein referred to as film elements. The regions of the force-sensitive film or the film elements may also be connected to sense circuitry using electrically conductive traces or electrodes. FIG. 12 depicts a cross-sectional view of a device having a strain-based force sensor 1200 formed from one or more strain pixel elements 1202 and 1204 separated by intermediate layer 1206. Each of the pixel elements 1202, 1204 may be separated by a gap 1210. In the present example, each pixel element 1202, 1204 may exhibit a measurable change in an electrical property in response to a force being applied to the device. By way of example, as a force is applied to a surface 1211 on the cover 609, one or more of the pixel elements 1202, 1204 is deflected or deformed. Sense circuitry, which is in electrical communication with the one or more pixel elements 1202, 1204, may be configured to detect and measure the change in the electrical property of the film due to the deflection. Based on the measured electrical property of the pixel elements 1202, 1204, an estimated amount of force can be computed. In some cases, the estimated force may represent the magnitude of a touch on the surface 1211 of the device, and be used as an input to a graphical user interface or other element of the device. Additionally, in some embodiments, the relative strain of the individual pixel elements may be compared to estimate a location of the touch. While FIG. 12 depicts an example force sensor 1200 having two layers of pixel elements, alternative embodiments may include only a single layer of pixel elements or, alternatively, include more than two layers of pixel elements.

The pixel elements 1202, 1204 may be specifically configured to detect strain along one or more directions. In some

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cases, each pixel element **1202**, **1204** includes an array of traces generally oriented along one direction. This configuration may be referred to as a piezo-resistive or resistive strain gauge configuration. In general, in this configuration the force-sensitive-film is a material whose resistance changes in response to strain. The change in resistance may be due to a change in the geometry resulting from the applied strain. For example, an increase in length combined with decrease in cross-sectional area may occur in accordance with Poisson's effect. The change in resistance may also be due to a change in the inherent resistivity of the material due to the applied strain. For example, the applied strain may make it easier or harder for electrons to transition through the material. The overall effect is for the total resistance to change with strain due to the applied force.

Further, in a piezo-resistive or resistive strain gauge configuration, each pixel may be formed from a pattern of the force-sensitive-film, aligned to respond to strain along a particular axis. For example, if strain along an x-axis is to be measured, the pixel should have a majority of its trace length aligned with the x-axis. By way of example, FIG. 13A depicts a pixel element **1302** having traces that are generally oriented along the x-axis and may be configured to produce a strain response that is substantially isolated to strain in the x-direction. Similarly, FIG. 13B depicts a pixel element **1304** having traces that are generally oriented along the y-axis and may be configured to produce a strain response that is substantially isolated to strain in the y-direction.

In some embodiments, the force-sensitive film may be formed from a solid sheet of material and is in electrical communication with a pattern of electrodes disposed on one or more surfaces of the force-sensitive film. The electrodes may be used, for example, to electrically connect a region of the solid sheet of material to sense circuitry. This configuration may be referred to as a piezo-strain configuration. In this configuration, the force-sensitive film may generate a charge when strained. The force-sensitive film may also generate different amounts of charge depending on the degree of the strain. In some cases, the overall total charge is a superposition of the charge generated due to strain along various axes.

As mentioned previously, a force sensor may be combined with a touch sensor that is configured to detect and measure the location of a touch on the surface of the device. FIG. 14A depicts a simplified schematic representation of an example mutual capacitance touch sensor. As shown in FIG. 14A, a touch sensor **1430** may be formed by an array of nodes **1402** formed at the intersection of an array of drive lines **1404** and sense lines **1406**. In this example, stray capacitance  $C_{stray}$  may be present at each node **1402** (although FIG. 14A depicts only one  $C_{stray}$  for one column for purposes of simplifying the figure). In the example of FIG. 14A, AC stimuli  $V_{stim}$  **1414**,  $V_{stim}$  **1415** and  $V_{stim}$  **1417** can be at different frequencies and phases. Each stimulation signal on a row can cause a charge  $Q_{sig} = C_{sig} \times V_{stim}$  to be injected into the columns through the mutual capacitance present at the affected nodes **1402**. A change in the injected charge ( $Q_{sig\_sense}$ ) can be detected when a finger, palm or other object is present at one or more of the affected nodes **1402**.  $V_{stim}$  signals **1414**, **1415** and **1417** can include one or more bursts of sine waves. Note that although FIG. 14A illustrates rows **1404** and columns **1406** as being substantially perpendicular, they need not be aligned, as described above. Each column **1406** may be operatively coupled to a receive channel of a charge-monitoring circuit.

FIG. 14B depicts a side view of an exemplary node in a steady-state (no touch) condition according to examples of

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the disclosure. In FIG. 14B, electric field lines **1408** between a column **1406** and a row **1404** separated by dielectric **1410** is shown at node **1402**.

FIG. 14C depicts a side view of an exemplary pixel in a dynamic (touch) condition. An object such as finger **1412** can be placed near node **1402**. Finger **1412** can be a low-impedance object at signal frequencies, and can have an AC capacitance  $C_{finger}$  from the column trace **1406** to the body. The body can have a self-capacitance to ground  $C_{body}$  of about 200 pF, where  $C_{body}$  can be much larger than  $C_{finger}$ . If finger **1412** blocks some electric field lines **1408** between row and column electrodes (those fringing fields that exit the dielectric **1410** and pass through the air above the row electrode), those electric field lines can be shunted to ground through the capacitance path inherent in the finger and the body, and as a result, the steady state signal capacitance  $C_{sig}$  can be reduced by  $DC_{sig}$ . In other words, the combined body and finger capacitance can act to reduce  $C_{sig}$  by an amount  $DC_{sig}$  (which can also be referred to herein as  $C_{sig\_sense}$ ), and can act as a shunt or dynamic return path to ground, blocking some of the electric field lines as resulting in a reduced net signal capacitance. The signal capacitance at the pixel becomes  $C_{sig} - DC_{sig}$ , where  $DC_{sig}$  represents the dynamic (touch) component. Note that  $C_{sig} - DC_{sig}$  may always be nonzero due to the inability of a finger, palm or other object to block all electric fields, especially those electric fields that remain entirely within the dielectric material. In addition, it should be understood that as finger **1412** is pushed harder or more completely onto the touch sensor, finger **1412** can tend to flatten, blocking more and more of the electric fields lines **1408**, and thus  $DC_{sig}$  may be variable and representative of how completely finger **1412** is pushing down on the panel (i.e., a range from "no-touch" to "full-touch").

Additionally or alternatively, the touch sensor may be formed from an array of self-capacitive pixels or electrodes. FIG. 15A depicts an example touch sensor circuit corresponding to a self-capacitance touch pixel electrode and sensing circuit. Touch sensor circuit **1509** can have a touch pixel electrode **1502** with an inherent self-capacitance to ground associated with it, and also an additional self-capacitance to ground that can be formed when an object, such as finger **1512**, is in proximity to or touching the touch pixel electrode **1502**. The total self-capacitance to ground of touch pixel electrode **1502** can be illustrated as capacitance **1504**. Touch pixel electrode **1502** can be coupled to sensing circuit **1514**. Sensing circuit **1514** can include an operational amplifier **1508**, feedback resistor **1516**, feedback capacitor **1510** and an input voltage source **1506**, although other configurations can be employed. For example, feedback resistor **1516** can be replaced by a switch capacitor resistor. Touch pixel electrode **1502** can be coupled to the inverting input of operational amplifier **1508**. An AC input voltage source **1506** can be coupled to the non-inverting input of operational amplifier **1508**. Touch sensor circuit **1509** can be configured to sense changes in the total self-capacitance **1504** of touch pixel electrode **1502** induced by finger **1512** either touching or in proximity to the touch sensor panel. Output **1520** can be used by a processor to determine a presence of a proximity or touch event, or the output can be inputted into a discreet logic network to determine the presence of a touch or proximity event.

FIG. 15B depicts an example self-capacitance touch sensor **1530**. Touch sensor **1530** can include a plurality of touch pixel electrodes **1502** disposed on a surface and coupled to sense channels in a touch controller, can be driven by stimulation signals from the sense channels through drive/sense interface **1525**, and can be sensed by the sense



channels through the drive/sense interface 1525 as well. After touch controller has determined an amount of touch detected at each touch pixel electrode 1502, the pattern of touch pixels in the touch screen panel at which touch occurred can be thought of as an “image” of touch (e.g., a pattern of fingers touching the touch screen). The arrangement of the touch pixel electrodes 1502 in FIG. 15B is provided as one example; however, the arrangement and/or the geometry of the touch pixel electrodes may vary depending on the embodiment.

As previously mentioned, a force sensor may be implemented alone or in combination with another type of touch sensor to sense both touch force and touch location, which may enable more sophisticated user touch input than using touch location alone. For example, a user may manipulate a computer-generated object on a display using a first type of interaction using a relatively light touch force at a given touch location. The user may also interact with the object using a second type of interaction by using a relatively heavy or sharper touch force at the given location. As one specific example, a user may manipulate or move a computer-generated object, such as a window, using a relatively light touch force. Additionally or alternatively, the user may also select or invoke a command associated with the window using a relatively heavy or sharper touch force. In some cases, multiple types of interactions may be associated with multiple amounts of touch force.

Additionally, it may be advantageous for the user to be able to provide an analog input using a varying amount of force. A variable, non-binary input may be useful for selecting within a range of input values. The amount of force may, in some cases, be used to accelerate a scrolling operation, a zooming operation, or other graphical user interface operation. It may also be advantageous to use the touch force in a multi-touch sensing environment. In one example, the force of a touch may be used to interpret a complex user input performed using multiple touches, each touch having a different magnitude or degree of force. As a specific but non-limiting example, touch and force may be used in a multi-touch application that allows the user to play a varying tone or simple musical instrument using the surface of the device. In such a housing, the force of each touch may be used to interpret a user’s interaction with the buttons or keys of a virtual instrument. Similarly, the force of multiple touches can be used to interpret a user’s multiple touches in a game application that may accept multiple non-binary inputs at different locations.

4. Sensor or Biosensor Module

As described above with respect to FIG. 2, a wearable electronic device may include one or more sensors that can be used to calculate a health metric or other health-related information. For the purposes of the following description of the biosensor module, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100 including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a wearable electronic device may function as a wearable health assistant that provides health-related information (whether real-time or not) to the user, authorized third parties, and/or an associated monitoring device. The wearable health assistant may be configured to provide health-related information or data such as, but not limited to, heart rate data, blood pressure data, temperature data, blood oxygen saturation level data, diet/nutrition information, medical reminders, health-related tips or informa-

tion, or other health-related data. The associated monitoring device may be, for example, a tablet computing device, phone, personal digital assistant, computer, and the like.

In accordance with some embodiments, the electronic device can be configured in the form of a wearable electronic device that is configured or configurable to provide a wide range of functionality. As described above with respect to FIG. 2, the wearable electronic device 100 may include a processing units 102 coupled with or in communication with a memory 104, one or more communications channels 108, output devices such as a display 120 and speaker 122, one or more input components 106, and other modules or components. An example wearable electronic device 100 may be configured to provide or calculate information regarding time, health information, biostatistics, and/or status to externally connected or communicating devices and/or software executing on such devices. The device 100 may also be configured to send and receive messages, video, operating commands, and other communications.

With reference to FIG. 16, an example device 100 may include various sensors for measuring and collecting data that may be used to calculate a health metric or other health-related information. As one example, the wearable communication device can include an array of light sources 1611-1613 and a detector 1614 that are configured to function as an optical sensor or sensors. In one example, an optical sensor or sensors may implemented as a pairing of one or more light sources 1611-1613 and the detector 1614. In one example implementation, the detector 1614 is configured to collect light and convert the collected light into an electrical sensor signal that corresponds to the amount of light incident on a surface of the detector 1614. In one embodiment, the detector may be a photodetector, such as a photodiode. In other embodiments, the detector 1614 may include a phototube, photosensor, or other light-sensitive device.

In some cases, the one or more optical sensors may operate as a photoplethysmography (PPG) sensor or sensors. In some instances, a PPG sensor is configured to measure light and produce a sensor signal that can be used to estimate changes in the volume of a part of a user’s body. In general, as light from the one or more light sources passes through the user’s skin and into the underlying tissue, some light is reflected, some is scattered, and some light is absorbed, depending on what the light encounters. The light that is received by the detector 1614 may be used to generate a sensor signal, which may be used to estimate or compute a health metric or other physiological phenomena.

The light sources may operate at the same light wavelength range, or the light sources can operate at different light wavelength ranges. As one example, with two light sources, one light source may transmit light in the visible wavelength range while the other light source can emit light in the infrared wavelength range. In some cases, a modulation pattern or sequence may be used to turn the light sources on and off and sample or sense the reflected light. With reference to FIG. 16, the first light source 1611 may include, for example, a green LED, which may be adapted for detecting blood perfusion in the body of the wearer. The second light source 1612 may include, for example, an infrared LED, which may be adapted to detect changes in water content or other properties of the body. The third 1613 light source may be a similar type or different types of LED element, depending on the sensing configuration.

The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics, including, without limitation, a heart rate, a respiration rate, blood oxygenation level,

a blood volume estimate, blood pressure, or a combination thereof. In some instances, blood may absorb light more than surrounding tissue, so less reflected light will be sensed by the detector of the PPG sensor when more blood is present. The user's blood volume increases and decreases with each heartbeat. Thus, in some cases, a PPG sensor may be configured to detect changes in blood volume based on the reflected light, and one or more physiological parameters of the user may be determined by analyzing the reflected light. Example physiological parameters include, but are not limited to, heart rate, respiration rate, blood hydration, oxygen saturation, blood pressure, perfusion, and others.

While FIG. 16 depicts one example embodiment, the number of light sources and/or detectors may vary in different embodiments. For example, another embodiment may use more than one detector. Another embodiment may also use fewer or more light sources than are depicted in the example of FIG. 16. In particular, in the example depicted in FIG. 16, the detector 1614 is shared between multiple light sources 1611-1613. In one alternative embodiment, two detectors may be paired with two corresponding light sources to form two optical sensors. The two sensors (light source/detector pairs) may be operated in tandem and used to improve the reliability of the sensing operation. For example, output of the two detectors may be used to detect a pulse wave of fluid (e.g., blood) as it passes beneath the respective detectors. Having two sensor readings taken at different locations along the pulse wave may allow the device to compensate for noise created by, for example, movement of the user, stray light, and other effects.

In some implementation, one or more of the light sources 1611-1613 and the detector 1614 may also be used for optical data transfer with a base or other device. For example, the detector 1614 may be configured to detect light produced by an external mating device, which may be interpreted or translated into a digital signal. Similarly, one or more of the light sources 1611-1613 may be configured to transmit light that may be interpreted or translated into a digital signal by an external device.

Returning to FIG. 16, the device 100 may also include one or more electrodes to measure electrical properties of the user's body. In this example, a first electrode 1601 and second electrode 1602 are disposed on the rear face of the device 100. The first 1601 and second 1602 electrodes may be configured to make contact with the skin of the user's wrist when the device is being worn. As shown in FIG. 16, a third electrode 1603 and fourth electrode 1604 may be disposed along a periphery of the device body 610. In the configuration of FIG. 16, the third 1603 and fourth 1604 electrodes are configured to come into contact with the skin of the user's other hand (that is not wearing the device 100). For example, the third 1603 and fourth 1604 electrodes may be contacted when the user pinches the device 100 between two digits (e.g., a forefinger and thumb).

FIG. 16 depicts one example arrangement of electrodes. However, in other embodiments, one or more of the electrodes may be placed in locations that are different than the configuration of FIG. 16. For example, one or more electrodes may be placed on a top surface or other surface of the device 100. Additionally, fewer electrodes or more electrodes may be used to contact the user's skin, depending on the configuration.

Using the electrodes of the device, various electrical measurements may be taken, which may be used to compute a health metric or other health-related information. By way of example, the electrodes may be used to detect electrical activity of the user's body. In some cases, the electrodes may

be configured to detect electrical activity produced by the heart of the user to measure heart function or produce an electrocardiograph (ECG). As another example, the electrodes of the device may be used to detect and measure conductance of the body. In some cases, the measured conductance may be used to compute a galvanic skin response (GSR), which may be indicative of the user's emotional state or other physiological condition. By way of further example, the electrodes may also be configured to measure other health characteristics, including, for example, a body fat estimate, body or blood hydration, and blood pressure.

In some embodiments, the optical sensors and electrodes discussed above with respect to FIG. 16 may be operatively coupled to sensing circuitry and the processing units 102 to define a health monitoring system. In this capacity, the processing units 102 may be any suitable type of processing device. In one embodiment, the processing units 102 include a digital signal processor. The processing units 102 may receive signals from the optical sensor(s) and/or electrodes and process the signals to correlate the signal values with a physiological parameter of the user. As one example, the processing units 102 can apply one or more demodulation operations to the signals received from the optical sensor. Additionally, the processing units 102 may control the modulation (i.e., turning on and off) of the light sources according to a given modulation pattern or sequence. The processing units 102 may also be used to calculate one or more biometrics or other health related information.

In some implementations, the wearable electronic device may also receive sensor data or output from an external device. For example, an external mobile device having a global positioning system (GPS) may relay location information to the wearable device, which may be used to calibrate an activity metric, such as a pedometer or distance calculator. Similarly, sensor output of the wearable electronic device may be transmitted to an external device to compute health-related information. For example, output from an accelerometer in the wearable electronic device may be used to determine a body position or gesture, which may be relayed to an external device and used to compute health-related information, such as activity level.

In some embodiments, some or all of the biosensors may be integrated into a module that is separate from and attached to the housing 601 of the device 100. As described above with respect to FIG. 6, in some embodiments, the biosensors are disposed relative to or attached to a rear cover 608 that is formed from an optically transparent material and is configured to be positioned with the opening of the housing 601. In some embodiments, the rear cover 608 is disposed completely within the area of the cover so that the two components completely overlap when viewed from above. In some embodiments, the rear cover 608 has an edge that protrudes outwardly from the back surface of the housing 601. In some embodiments, an edge of the rear cover 608 extends past a flat portion of the back surface of the housing 601. The rear cover 608 may also have a convex, curved outer contour. The rear cover 608 may have a convex shape that is located within the center and surrounded by the edges of the rear cover 608. The convex curved area of the rear cover 608 may include one or more windows or apertures that provide operational access to one or more internal components located within the housing. For example, the rear cover 608 may include an array of windows, each window including an aperture or opening for a respective light source 1611-1613 and/or the detector 1614. In some embodiments, the windows have a curvature



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that matches the curvature of the convex curved area of the rear cover 608. In some embodiments, rear cover 608 includes a chamfered edge and a curved bottom surface, the windows being disposed within the curved surface. In some embodiments, two openings of the rear cover 608 are located along a first axis (e.g., an x-axis) and two openings are located along a second axis (e.g., a y-axis) that is transverse to the first axis.

#### 5. Example Wireless Communications with External Devices

A wearable electronic device may include a functionality for performing wireless communications with an external device. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, the wireless communications are performed in accordance with a Near Field Communications (NFC) protocol. The communication may include an identification protocol and a secured data connection that can be used to identify the user, authorize activity, perform transactions, or conduct other aspects of electronic commerce.

FIG. 17 depicts an example system 1700 including a device 100 that is located proximate to a station 1710. The station 1710 may include a variety of devices, including, without limitation, a payment kiosk, a vending machine, a security access point, a terminal device, or other similar device. In some cases, the station 1710 is incorporated into a larger system or device. For example, the station 1710 may be incorporated into a security gate of a building or a payment center for a vending system.

As shown in FIG. 17, the device 100 is a wearable electronic device that may be placed proximate to the station 1710. In this example, a second device 1720 is carried by a user, and may also be placed proximate to the station 1710. In some embodiments, the device 100 and/or the second device 1720 includes a radio-frequency identification (RFID) system that is configured to enable one-way or two-way radio-frequency (RF) communications with the station 1710. The one- or two-way communication may include an identification of the device 100 and the station 1710 to initiate a secured data connection between the two devices. The secured data connection may be used to authorize a transaction between the user and an entity that is associated with the station 1710.

In some embodiments, the user may initiate a communication with the station 1710 by placing the device 100 near an active region on the station 1710. In some implementations, the station 1710 is configured to automatically detect the presence of the device 100 and initiate an identification process or routine. The RFID system of the device may include a unique identifier or signature that may be used to authenticate the identity of the user. As previously mentioned, the identification process or routine may be used to establish a secure data connection between the device 100 and the station 1710. The secure data connection may be used to authorize a purchase or download of data to or from the device 100. In some cases, the secure data connection may be used to authorize the transfer of funds from a credit card or financial institution in exchange for a product that is associated with the station 1710. Other transactions or forms of electronic commerce may also be performed using the wireless communication between the device 100 and the station 1710.

#### 6. Example Wireless Power System

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As discussed above, a wearable electronic device may include an internal battery that is rechargeable using an external power source. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

One challenge associated with small devices is that it may be difficult to incorporate an electrical port for coupling the device to an external power source. Because wearable electronic devices have limited space for an external connector, it may be advantageous to electrically couple to a device without a cable or external connector. In at least some embodiments, the wearable electronic device described herein may be configured to operate as a receiver in a wireless power transfer system.

A wireless power transfer system, one example of which is an inductive power transfer system, typically includes a power-transmitting structure to transmit power and a power-receiving structure to receive power. In some examples, a power-receiving electronic device includes or otherwise incorporates an inductive power-receiving element configured to receive wireless power and/or charge one or more internal batteries. Similarly, a charging device may include or otherwise incorporate an inductive power-transmitting element configured to wirelessly transmit power to the power-receiving electronic device. The charging device may be configured as a base or dock on which the power-receiving electronic device rests or to which it physically connects in some embodiments. In other embodiments, the charging device may be proximate the electronic device but not necessarily touching or physically coupled.

In many examples, the battery-powered electronic device may be positioned on an external surface of the power-transmitting device, otherwise referred to as a dock. In these systems, an electromagnetic coil within the dock (e.g., transmit coil) may produce a time-varying electromagnetic flux to induce a current within an electromagnetic coil within the electronic device (e.g., receive coil). In many examples, the transmit coil may transmit power at a selected frequency or band of frequencies. In one example the transmit frequency is substantially fixed, although this is not required. For example, the transmit frequency may be adjusted to improve inductive power transfer efficiency for particular operational conditions. More particularly, a high transmit frequency may be selected if more power is required by the electronic device and a low transmit frequency may be selected if less power is required by the electronic device. In other examples, a transmit coil may produce a static electromagnetic field and may physically move, shift, or otherwise change its position to produce a spatially-varying electromagnetic flux to induce a current within the receive coil.

The electronic device may use the received current to replenish the charge of a rechargeable battery or to provide power to operating components associated with the electronic device. Thus, when the electronic device is positioned on the dock, the dock may wirelessly transmit power at a particular frequency via the transmit coil to the receive coil of the electronic device.

A transmit coil and receive coil may be disposed respectively within housings of the dock and electronic device so as to align along a mutual axis when the electronic device is placed on the dock. If misaligned, the power transfer efficiency between the transmit coil and the receive coil may decrease as misalignment increases. Accordingly, in many

examples, the wireless power transfer system may include one or more alignment assistance features to effect alignment of the transmit and receive coils along the mutual axis.

FIG. 18 depicts a front perspective view of an example wireless power transfer system 1800 in an unmated configuration. The illustrated embodiment shows an inductive power transmitter dock 1802 that is configured to couple to and wirelessly transmit power to an inductive power receiver accessory, in this case device 100. The wireless power transfer system 1800 may include one or more alignment assistance features to effect alignment of the device 100 with the dock 1802 along a mutual axis. For example, the housings of the dock 1802 and the device 100 may assist with alignment. In one implementation, a portion of the housing of the device 100 may engage and/or interlock with a portion of the housing of the dock 1802 in order to effect the desired alignment. In some embodiments, a bottom portion of the device 100 may be substantially convex and a top surface of the dock 1802 may be substantially concave. In other examples, the interfacing surfaces of the dock 1802 and the device 100 may be substantially flat, or may include one or more additional housing features to assist with effecting mutual alignment.

In some embodiments, one or more actuators in the dock 1802 and/or device 100 can be used to align the transmitter and receiver devices. In yet another example, alignment assistance features, such as protrusions and corresponding indentations in the housings of the transmitter and receiver devices, may be used to align the transmitter and receiver devices. The design or configuration of the interface surfaces, one or more alignment assistance mechanisms, and one or more alignment features can be used individually or in various combinations thereof.

Alignment assistance can also be provided with one or more magnetic field sources. For example, a permanent magnet within the dock 1802 may attract a permanent magnet within the device 100. In another example, a permanent magnet within the device 100 may be attracted by a magnetic field produced by the dock 1802. In further examples, multiple alignment assistance features may cooperate to effect alignment of the transmit and receive coils. Power transfer efficiency may also decrease if the power consumption of the electronic device changes (e.g., the electronic device transitions from a trickle charge mode to constant current charge mode) during wireless power transfer.

As discussed previously with respect to FIG. 2, the device 100 may include a processor coupled with or in communication with a memory, one or more communication interfaces, output devices such as displays and speakers, and one or more input devices such as buttons, dials, microphones, or touch-based interfaces. The communication interface(s) can provide electronic communications between the communications device and any external communication network, device or platform, such as, but not limited to, wireless interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. The device 100 may provide information regarding time, health, statuses or externally connected or communicating devices and/or software executing on such devices, messages, video, operating commands, and so forth (and may receive any of the foregoing from an external device), in addition to communications.

In the example depicted in FIG. 18, the dock 1802 may be connected to an external power source, such as an alternat-

ing current power outlet, by power cord 1808. In other embodiments, the dock 1802 may be battery operated. In still further examples, the dock 1802 may include a power cord 1808 in addition to an internal or external battery. Similarly, although the embodiment is shown with the power cord 1808 coupled to the housing of the dock 1802, the power cord 1808 may be connected by any suitable means. For example, the power cord 1808 may be removable and may include a connector that is sized to fit within an aperture or receptacle opened within the housing of the dock 1802.

Although the device 100 is shown in FIG. 18 as larger than the dock 1802, the depicted scale may not be representative of all embodiments. For example, in some embodiments the dock 1802 may be larger than the device 100. In still further embodiments the two may be substantially the same size and shape. In other embodiments, the dock 1802 and device 100 may take separate shapes.

FIG. 19 depicts a simplified block diagram of relevant aspects of the device 100 and dock 1802. It may be appreciated that certain components of both the dock 1802 and device 100 are omitted from the figure for clarity. Likewise, the positions of the elements that are shown are meant to be illustrative rather than necessarily portraying a particular size, shape, scale, position, orientation, or relation to one another, although some embodiments may have elements with one or more of such factors as illustrated.

As described previously with respect to FIG. 2, the device 100 may include one or more electronic components located within the housing 601. For clarity, some of the components and modules described or depicted in various embodiments are omitted from the depiction of FIG. 19. As shown in FIG. 19, the device 100 may include an internal battery 114 that may be used to provide power to the various internal components of the device 100. As described previously, the internal battery 114 may be rechargeable by an external power supply. In the present example, the internal battery 114 is operably connected to a receive coil 1869 via power conditioning circuit 1810.

In the present example, the device 100 includes a receive coil 1869 having one or more windings for inductively coupling with a transmit coil 1832 of the dock 1802. The receive coil 1869 may receive power wirelessly from the dock 1802 and may pass the received power to a battery 114 within the device 100 via power conditioning circuit 1810. The power conditioning circuit 1810 may be configured to convert the alternating current received by the receive coil 1869 into direct current power for use by other components of the device. In one example, the processing units 102 may direct the power, via one or more routing circuits, to perform or coordinate one or more functions of the device 100 typically powered by the battery 114.

As shown in FIG. 19, the dock 1802 includes a transmit coil 1832 having one or more windings. The transmit coil 1832 may transmit power to the device 100 via electromagnetic induction or magnetic resonance. In many embodiments, the transmit coil 1832 may be shielded with a shield element that may be disposed or formed around portions of the transmit coil 1832. Similarly, the receive coil 1869 may also include a shield element that may be disposed or formed around a portion of the receive coil 1869.

As shown in FIG. 19, the dock 1802 also includes a processor 1834 that may be used to control the operation of or coordinate one or more functions of the dock 1802. In some embodiments, the dock 1802 may also include one or more sensors 1836 to determine whether the device 100 is present and ready to receive transmitted power from the dock 1802. For example, the dock 1802 may include an



optical sensor, such as an infrared proximity sensor. When the device 100 is placed on the dock 1802, the infrared proximity sensor may produce a signal that the processor 1834 uses to determine the presence of the device 100. The processor 1834 may, optionally, use another method or structure to verify the presence of the electronic device via sensor 1836. Examples of different sensors that may be suitable to detect or verify the presence of device 100 may include a mass sensor, a mechanical interlock, switch, button or the like, a Hall effect sensor, or other electronic sensor. Continuing the example, after the optical sensor reports that the device 100 may be present, the processor 1834 may activate a communication channel to attempt to communicate with the device 100.

As illustrated in FIG. 19, a bottom surface of the housing of the device 100 may partially contact a top surface of the dock housing. In some implementations, the interfacing surfaces of the device 100 and the dock 1802 may be formed with complementary geometries. For example, as depicted in FIG. 19, the bottom surface of the device 100 is convex and the top surface of the dock 1802 is concave, following the same curvature as the bottom surface of the device 100. In this manner, the complementary geometries may facilitate alignment of the electronic device and dock for efficient wireless power transfer.

In some embodiments, the dock 1802 and device 100 may include other alignment assistance features. For example the device 100 may include an alignment magnet 1838 which is positioned and oriented to attract a corresponding alignment magnet 1840 within the dock 1802. In some cases, when the device 100 is positioned proximate the dock 1802, the alignment magnets 1838, 1840 may be mutually attracted, thereby affecting alignment of the portable electronic device 100 and the dock 1802 along a mutual axis. In other examples, the dock 1802 may include a ferromagnetic material in place of the alignment magnet 1840. In these examples, the alignment magnet 1838 may be attracted to the ferromagnetic material. In still further cases, the receive coil 1869 or transmit coil 1832 may produce a static magnetic field that either attracts or repels either or both of the alignment magnets 1838, 1840.

As shown in FIG. 19, the alignment magnets 1838, 1840 may be positioned within a respective coil 1869, 1832. When the alignment magnets 1838, 1840 are drawn together, the coils 1869, 1832 may be placed into alignment. Additionally, the complementary geometries of the device 100 and the dock 1802 may further facilitate alignment when the alignment magnets 1838, 1840 are drawn together.

7. Example Acoustic Module

As described above, the device may include one or more devices for transmitting and receiving acoustic energy. For the purposes of the following description of the acoustic module, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above. As previously discussed, in some embodiments, the device may include a speaker for transmitting acoustic energy and/or a microphone for receiving acoustic energy. For the purposes of the following description, a speaker device and a microphone are referred to generically as an acoustic module, which may be configured to transmit and/or receive acoustic energy depending on the particular implementation.

FIG. 20 depicts a simplified schematic cross-sectional view of a first embodiment of a device having an acoustic module 2006. The representation depicted in FIG. 20 is not

drawn to scale and may omit some elements for clarity. The acoustic module 2006 may represent either a portion of a speaker and/or microphone device described above with respect to the electronic device 100 of FIG. 2.

As shown in FIG. 20, an acoustic port 2020 may be formed in the housing 601 of the electronic device. In the present example, the acoustic port 2020 includes first and second orifices 2031, 2032 that are formed in the housing 601 and acoustically couple the acoustic cavity 2011 of the acoustic module 2006 to the external environment (external to the electronic device). In the present embodiment, the first and second orifices 2031, 2032 are offset with respect to the opening of the acoustic cavity 2011. This configuration may help reduce the direct ingress of liquid 2001 into acoustic cavity 2011 of the acoustic module 2006. Also, as shown in FIG. 20 a shield 2021 or umbrella structure that is formed between the orifices 2031, 2032 blocks the direct ingress of liquid 2001 into the acoustic cavity 2011. As shown in FIG. 20, the acoustic module 2006 also includes a screen element 2015 disposed at one end of the acoustic cavity 2011, which may also prevent the ingress of liquid or other foreign debris into the acoustic cavity 2011. The acoustic module 2006 also includes a seal 2016 disposed between the housing 601 and the connector element 2012 of the module, which may also be configured to prevent the ingress of water into the device and/or module.

In the present example depicted in FIG. 20, the acoustic module 2006 may correspond to the speaker 122 described with respect to some embodiments. As shown in FIG. 20, the acoustic module 2006 includes various components for producing and transmitting sound, including a diaphragm 2010, a voice coil 2009, a center magnet 2008, and side magnets/coils 2007. These components may cooperate to form a speaker acoustic element. In one implementation, the diaphragm 2010 is configured to produce sound waves or an acoustic signal in response to a stimulus signal in the center magnet 2008. For example, a modulated stimulus signal in the center magnet 2008 causes movement of the voice coil 2009, which is coupled to the diaphragm 2010. Movement of the diaphragm 2010 creates the sound waves, which propagate through the acoustic cavity 2011 of acoustic module 2006 and eventually out the acoustic port 2020 to a region external to the device. In some cases, the acoustic cavity 2011 functions as an acoustical resonator having a shape and size that is configured to amplify and/or dampen sound waves produced by movement of the diaphragm 2010.

As shown in FIG. 20, the acoustic module 2006 also includes a yoke 2014, support 2013, connector element 2012, and a cavity wall 2017. These elements provide the physical support of the speaker elements. Additionally, the connector element 2012 and the cavity wall 2017 together form at least part of the acoustic cavity 2011. The specific structural configuration of FIG. 20 is not intended to be limiting. For example, in alternative embodiments, the acoustic cavity may be formed from additional components or may be formed from a single component.

The acoustic module 2006 depicted in FIG. 20 is provided as one example of a type of speaker acoustic module. In other alternative implementations, the acoustic module may include different acoustic elements for producing and transmitting sound, including, for example, a vibrating membrane, piezoelectric transducer, vibrating ribbon, or the like. Additionally, in other alternative implementations, the acoustic module may be a microphone acoustic module having one or more elements for converting acoustic energy into an electrical impulse. For example, the acoustic module

may alternatively include a piezoelectric microphone acoustic element for producing a charge in response to acoustic energy or sound.

As previously mentioned, because the acoustic port 2020 connects the acoustic module 2006 to the external environment, there is a possibility that liquid may accumulate or infiltrate the interior of the module. In some cases, the screen element 2015 or other protective features may not prevent all liquid from entering the acoustic cavity 2011 of the module. For example, if the device is subjected to a liquid under pressure or a directed stream of liquid, some liquid ingress may occur. Additionally, naturally occurring moisture in the air may condense and accumulate over time resulting in the presence of liquid within the module. Thus, in some implementations, the acoustic module 2006 may include one or more elements configured to expel water or liquid that accumulates in, for example, the acoustic cavity 2011 of the module. The liquid expulsion process may include modifying the charge on a portion of the wall of the acoustic cavity 2011 to change the surface energy of the wall and/or producing an acoustic pulse using the diaphragm 2010 to help expel liquid from the acoustic cavity 2011. In some embodiments, the screen 2015 may also have hydrophilic or hydrophobic properties that may facilitate removal of liquid held within the acoustic cavity 2011.

8. Example Antenna and Cover

As previously described, a wearable electronic device may be configured to communicate wirelessly with various external devices and communication networks. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, as previously discussed with respect to FIG. 2, the device may include one or more communication channels that are configured to transmit and receive data and/or signals over a wireless communications network or interface. Example wireless interfaces include radio frequency cellular interfaces, Bluetooth interfaces, Wi-Fi interfaces, or any other known communication interface.

In some implementations an antenna may be disposed with respect to the cover (e.g., crystal) of a device to facilitate wireless communications with an external device or communication network. In some cases, it may be advantageous to integrate an antenna into the cover to improve the transmission and reception of wireless signals from the device. In particular, the cover of the device may have dielectric properties that facilitate the transmission of radio frequency signals while also protecting the antenna from physical damage or interference. Additionally, if the antenna is integrated into a perimeter portion of the cover, the visual appearance or clarity of the cover may be minimized. Furthermore, the embodiments described below with respect to FIGS. 21A-B may be used to integrate an antenna external to the housing, without increasing the thickness of the device body.

FIG. 21A depicts a perspective exploded view of a cover 2100 and an antenna assembly 2130. The cover 2100 depicted in FIG. 21A is viewed from an inner surface 2124 that is configured to attach to or interface with the opening of the housing (described above with respect to FIG. 1). As shown in FIG. 21A, a groove 2128 may be formed within the inner surface 2124. In this example, the groove 2128 is formed around the periphery of the cover 2100. As men-

tioned previously, this may be advantageous in minimizing the visual impact of having the antenna assembly 2130 located within the cover 2100.

As shown in FIG. 21A the antenna assembly 2130 includes an antenna ring 2134 and a terminal 2140 which may interface with an electrical connector 2150. In the present embodiment, the groove 2128 formed in the surface of the cover 2100 may be configured to accept the antenna ring 2134. In particular, the groove 2128 may receive the entire antenna ring 2134 without a portion of the antenna ring 2134 protruding past the inner surface 2124, when the antenna ring 2134 is installed. In some cases, the groove 2128 is formed to be a clearance or near clearance fit with the diameter of the antenna ring 2134. Thus, in some cases, the antenna ring 2134 may substantially fill the groove 2128 when the ring is installed. In some cases, the groove 2128 may be configured to retain the antenna ring 2134 due to a slight interference fit or due to a feature formed within either the cover 2100 and/or the antenna assembly 2130. In the present embodiment, the antenna assembly 2130 may be installed in the cover 2100 and then connected to other electronics via the terminal 2140 and the connector 2150, which may protrude into an opening in the case or housing.

FIG. 21B depicts a cross-sectional view of the cover and antenna at the connection point. In particular, FIG. 21B depicts a detail cross-sectional view of the cover 2100 installed within the housing 601 at a region near the terminal 2140. In this example, the cover 2100 is attached to a shelf of the housing 601 via a compressible element 2122. The compressible element 2122 may provide a seal against water or other contaminants and also provide compliance between the cover 2100 and the housing 601. The compressible element 2122 may be formed from a nitrile or silicone rubber and may also include an adhesive or other bonding agent.

As shown in FIG. 21B, the antenna ring 2134 is disposed entirely within the groove 2128. In this case, the antenna ring 2134 does not protrude past the inner surface 2124. The antenna ring 2134 is electrically connected to the terminal 2140, which protrudes into an opening in the housing 601. As shown in FIG. 21B, the terminal 2140 includes conductive pads 2142 for electrically connecting to the antenna ring 2134. In this example, spring clips 2152 are configured to mechanically and electrically connect to the conductive pads 2142 on the terminal 2140. One advantage to the configuration depicted in FIG. 21B is that the antenna assembly 2130 may be installed in the cover 2100 before the cover 2100 is installed in the housing 601. The terminal 2140 and connector 2150 facilitate a blind connection that may assist electrical connection as the cover 2100 is installed. Additionally, the configuration depicted in FIG. 21B may allow for some movement between the cover 2100 and the housing 601 without disturbing the electrical connection with the antenna ring 2134.

9. Example Haptic Module

As described above, the device may include one or more haptic modules for providing haptic feedback to the user. The embodiments described herein may relate to or take the form of durable and thin haptic feedback elements suitable to provide a perceivable single pulse haptic feedback. In general, a haptic device may be configured to produce a mechanical movement or vibration that may be transmitted through the housing and/or other component of the device. In some cases, the movement or vibration may be transmitted to the skin of the user and perceived as a stimulus or haptic feedback by the user. In some implementations, the haptic feedback may be coupled to one or more device



outputs to alert the user of an event or activity. For example, a haptic output may be produced in combination with an audio output produced by the speaker, and/or a visual output produced using the display.

The space constraints associated with a small wrist-worn device may present unique challenges to integrating a haptic mechanism into wearable electronics. In particular, a haptic mechanism may use a moving mass used to create the movement or vibration of the haptic output. The larger the mass that is moved, the easier it may be to create a perceivable stimulus using the haptic mechanism. However, a large moving mass and the supporting mechanism may be difficult to integrate into the compact space of, for example, the housing of a wearable electronic wristwatch.

Thus, the haptic module implemented in some embodiments may be configured to maximize the mechanical energy that is produced in a very compact form factor. FIGS. 22A-B depict one example haptic mechanism that may be particularly well suited for use in a wearable electronic device. While the embodiment described with respect to FIGS. 22A-B is provided as one example, the haptic module is not limited to this particular configuration.

FIG. 22A depicts a three-quarters perspective view of a haptic device 112, with a top, front and left sidewall of the housing 2220 removed to expose internal components. FIG. 22B depicts a cross-sectional perspective view of the haptic device 112 cut in half to expose the internal components. In this example, a coil 2200 is used to induce movement of a frame 2260, which houses a central magnet array 2210. As shown in FIGS. 22A-B, the movement of the frame 2260 is guided by a shaft 2250 that is fixed with respect to a housing 2220.

In the present example, the coil 2200 may be energized by transmitting a current (e.g., from the battery) along a length of a wire that forms the coil 2200. A direction of the current along the wire of the coil 2200 determines a direction of a magnetic field that emanates from the coil 2200. In turn, the direction of the magnetic field determines a direction of movement of the frame 2260 housing the central magnet array 2210. One or more springs may bias the frame 2260 towards the middle region of the travel. In this example, the frame 2260 and central magnet array 2210, through operation of the coil 2200, function as a moving mass, which generates a tap or vibration. The output of the haptic device 112, created by the moving mass of the frame 2260 and central magnet array 2210, may be perceived as a haptic feedback or stimulus to the user wearing the device.

For example, when the coil 2200 is energized, the coil 2200 may generate a magnetic field. The opposing polarities of the magnets in the magnet array 2210 generates a radial magnetic field that interacts with the magnetic field of the coil 2200. The Lorentz force resulting from the interaction of the magnetic fields causes the frame 2260 to move along the shaft 2250 in a first direction. Reversing current flow through the coil 2200 reverses the Lorentz force. As a result, the magnetic field or force on the central magnet array 2210 is also reversed and the frame 2260 may move in a second direction. Thus, frame 2260 may move in both directions along the shaft 2250, depending on the direction of current flow through the coil 2200.

As shown in FIG. 22A, the coil 2200 encircles the central magnet array 2210, which is disposed near the center of the frame 2260. As previously described, the coil 2200 may be energized by transmitting a current along the length of the wire forming the coil 2200, and the direction of the current flow determines the direction of the magnetic flux emanating from the coil 2200 in response to the current. Passing an

alternating current through the coil 2200 may cause the central magnet array 2210 (and frame 2260) to move back and forth along a shaft 2250. In order to prevent the central magnet array 2210 from being attracted to the shaft 2250, which could increase friction between the two and thereby increase the force necessary to move the central magnet array 2210 and frame 2260, the shaft 2250 may be formed from a non-ferrous material such as tungsten, titanium, stainless steel, or the like.

As depicted in FIGS. 22A-B, the coil 2200 is positioned within a frame 2260 that holds the central magnet array 2210, but is not affixed to the coil 2200. Rather, an air gap separates the coil 2200 from the central magnet array 2210 and the frame 2260 is free to move with respect to the coil 2200, which is generally stationary. Further, the frame 2260 generally moves with the central magnet array 2210. As illustrated in FIGS. 22A-B, the frame 2260 may have an aperture formed therein of sufficient size to contain the coil 2200. Even when the frame and central magnet array are maximally displaced within the housing 2220 (e.g., to one end or the other of the shaft 2250), the coil 2200 does not contact any portion of the frame 2260. It should be appreciated that the coil 2200 remains stationary in the housing 2220 while the frame 2260 and central magnet array 2210 move, although in other embodiments the coil 2200 may move instead of, or in addition to, the frame and/or central magnet array. However, by keeping the coil 2200 stationary, it may be easier to provide interconnections for the coil, such as between the coil and the flex, and therefore reduce the complexity of manufacture.

As shown in FIGS. 22A-B, the central magnet array 2210 may be formed from at least two magnets 2211, 2212 of opposing polarities. A center interface 2270 may be formed from a ferrous or non-ferrous material, depending on the embodiment. A ferrous material for the center interface 2270 may enhance the overall magnetic field generated by the central magnet array 2210, while a non-ferrous material may provide at least a portion of a return path for magnetic flux and thus assist in localizing the flux within the housing 2220. In some embodiments, the magnets 2211, 2212 are formed from neodymium while the frame is tungsten. This combination may provide a strong magnetic field and a dense mass, thereby yielding a high weight per volume structure that may be used as the moving part of the haptic device 112.

10. Example Crown Module

As described above, the device may include a crown that may be used to accept user input to the device. For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

In some embodiments, a crown may be used to accept rotary input from the user, which may be used to control aspects of the device. The crown may be knurled or otherwise textured to improve grip with the user's finger and/or thumb. In some embodiments, a crown may be turned by the user to scroll a display or select from a range of values. In other embodiments, the crown may be rotated to move a cursor or other type of selection mechanism from a first displayed location to a second displayed location in order to select an icon or move the selection mechanism between various icons that are output on the display. In a time keeping application, the crown may also be used to adjust the position of watch hands or index digits displayed on the display of the device. The crown may also be used to control

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the volume of a speaker, the brightness of the display screen, or control other hardware settings.

In some embodiments, the crown may also be configured to accept linear, as well as rotary, input. For example, the crown may be configured to translate along an axis when pressed or pulled by the user. In some cases, the linear actuation may be used as additional user input. The actuation may provide a binary output (actuated/not actuated) or may also provide a non-binary output that corresponds to the amount of translation along the axis of motion. In some instances, the linear input to the crown may be combined with the rotary input to control an aspect of the device.

The embodiments described herein may be used for at least a portion of the crown module integrated into a wearable electronic device. The embodiments are provided as examples and may not include all of the components or elements used in a particular implementation. Additionally, the crown module is not intended to be limited to the specific examples described below and may vary in some aspects depending on the implementation.

In some embodiments, an optical encoder may be used to detect the rotational motion of the crown. More specifically, the example provided below with respect to FIG. 23 may use an optical encoder to detect rotational movement, rotational direction and/or rotational speed of a component of the electronic device. Once the rotational movement, rotational direction and/or rotational speed have been determined, this information may be used to output or change information and images that are presented on a display or user interface of the electronic device.

Integrating an optical encoder into the space constraints of a typical wearable electronic device may be particularly challenging. Specifically, some traditional encoder configurations may be too large or delicate for use in a portable electronic device. The optical encoder described below may provide certain advantages over some traditional encoder configurations and may be particularly well suited for use with a crown module of a wearable electronic device.

As shown in the example embodiment of FIG. 23, the optical encoder of the present disclosure includes a light source 2370, a photodiode array 2380, and a shaft 2360. However, unlike typical optical encoders, the optical encoder of the present disclosure utilizes an encoding pattern disposed directly on the shaft 2360. For example, the encoding pattern includes a number of light and dark markings or stripes that are axially disposed along the shaft 2360. Each stripe or combination of stripes on the shaft 2360 may be used to identify a position of the shaft 2360. For example, as light is emitted from the light source 2370 and reflected off of the shaft 2360 into the photodiode array 2380, a position, rotation, rotation direction and rotation speed of the shaft 2360 may be determined. Once the rotation direction and speed are determined, this information may be used to output or change information or images that are presented on the display or user interface of the electronic device.

In other embodiments, the shape or form of the shaft of the encoder may be used to determine a position, rotation, rotation direction and rotation speed of the shaft. For example, the shaft may be fluted or have a number of channels that cause the light to be reflected in a number of different directions. Accordingly, a diffractive pattern may be used to determine the rotation, rotation direction and rotation speed of the shaft.

FIG. 23 illustrates a simplified depiction of the device 100 and crown module 642 in accordance with some embodiments. As shown in FIG. 23, the crown module 642 may be integrated with the housing 601 of the device 100 and may

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be formed from a dial 2340 disposed at the end of a shaft 2360. In the present embodiment, the crown module 642 also forms part of the optical encoder. As discussed above, the crown module 642 includes an optical encoder that includes a shaft 2360, a light source 2370, and a photodiode array 2380. Although a photodiode array is specifically mentioned, embodiments disclosed herein may use various types of sensors that are arranged in various configurations for detecting the movement described herein. For example, the movement of the shaft 2360 may be detected by an image sensor, a light sensor such as a CMOS light sensor or imager, a photovoltaic cell or system, photo resistive component, a laser scanner and the like.

The optical encoder may produce an encoder output that is used to determine positional data of the crown module 642. In particular, the optical encoder may produce an output that is used to detect that movement of the dial 2340 including the direction of the movement, speed of the movement and so on. The movement may be rotational movement, translational movement, angular movement, and so on. The optical encoder may also be used to detect the degree of the change of rotation of the dial 2340 and/or the angle of rotation of the dial 2340 as well as the speed and the direction of the rotation of the dial 2340.

The signals or output of the optical encoder may be used to control various aspects of other components or modules of the device. For example, continuing with the time keeping application example discussed above, the dial 2340 may be rotated in a clockwise manner in order to advance the displayed time forward. In one implementation, the optical encoder may be used to detect the rotational movement of the dial 2340, the direction of the movement, and the speed at which the dial 2340 is being rotated. Using the output from the optical encoder, the displayed hands of a time keeping application may rotate or otherwise move in accordance with the user-provided rotational input.

Referring back to FIG. 23, the crown module 642 may be formed from dial 2340 that is coupled to the shaft 2360. In some cases, the shaft 2360 and dial 2340 may be formed as a single piece. As the shaft 2360 is coupled to, or is otherwise a part of the dial 2340, as the dial 2340 rotates or moves in a particular direction and at a particular speed, the shaft 2360 also rotates or moves in the same direction and with the same speed.

As shown in FIG. 23, the shaft 2360 of the optical encoder includes an encoding pattern 2365. As discussed above, the encoding pattern 2365 may be used to determine positional information about the shaft 2360 including rotational movement, angular displacement and movement speed. As shown in FIG. 23, the encoding pattern 2365 may include a plurality of light and dark stripes.

Although light stripes and dark stripes are specifically mentioned and shown, the encoding pattern 2365 may consist of various types of stripes having various shades or colors that provide surface contrasts. For example, the encoding pattern 2365 may include a stripe or marking that has a high reflective surface and another stripe that has a low reflective surface regardless of the color or shading of the stripes or markings. In another embodiment, a first stripe of the encoding pattern 2365 may cause specular reflection while a second stripe of the encoding pattern 2365 may cause diffuse reflection. When the reflected light is received by the photodiode array 2380, a determination may be made as to the position and movement of the shaft such as described below. In embodiments where a holographic or diffractive pattern is used, the light from the light source 2370 may diffract from the shaft 2360. Based on the



diffracted light, the photodiode array 2380 may determine the position, movement and direction of movement of the shaft 2360.

In some embodiments, the stripes of the encoding pattern 2365 extend axially along the shaft 2360. The stripes may extend along the entire length of the shaft 2360 or partially along a length of the shaft 2360. In addition, the encoding pattern 2365 may also be disposed around the entire circumference of the shaft 2360. In other embodiments, the encoding pattern 2365 may include a radial component. In yet other embodiments, the encoding pattern 2365 may have both a radial component and an axial component.

In some embodiments, the crown module may also include a tactile switch for accepting translational input from the user. FIGS. 24A-B depict another example of a crown module 642a having a tactile switch assembly 2410. As shown in FIG. 24A, the tactile switch assembly 2410 may include a dial 2448 (or button), a coupling 2418, a shear plate 2456, and a tactile switch 2414.

In the embodiment depicted in FIGS. 24A-B, the dial 2448 is translatable and/or rotatable relative to the housing. The ability of the dial 2448 to translate and rotate relative to the housing allows a user to provide a rotational force and/or translating force to the tactile switch assembly. In particular, the dial 2448 of the present example may be operably coupled to or form part of an optical encoder, in accordance with the example described above with respect to FIG. 23.

In the present example, the dial 2448 includes an outer surface 2432 that is configured to receive a rotary or rotational user input and a stem 2450 that extends from an interior surface 2434 of the dial 2448. The stem 2450 may define a coupling aperture that extends longitudinally along a length or a portion of a length of the stem 2450. In the depicted example, the stem 2450 may be hollow or partially hollow.

In the example depicted in FIGS. 24A-B, the coupling 2418 may be a linkage, such as a shaft, that couples the dial 2448 to the tactile switch 2414. The coupling 2418 may be integrally formed with the dial 2448 or may be a separate component operably connected thereto. For example, the stem 2450 of the dial 2448 may form the coupling member that is integrally formed with the dial 2448. The coupling 2418 may be made of a conductive material, such as one or more metals or metal alloys. Due to the conductive characteristics, the coupling 2418 may further act to electrically couple the dial 2448 to the tactile switch 2414 and shear plate 2456. In the example depicted in FIGS. 24A-B, the shear plate 2456 is positioned between the coupling 2418 and the tactile switch 2414. In some embodiments, the shear plate 2456 may prevent or reduce shearing forces from the coupling from being transmitted to the tactile switch. The shear plate 2456 also allows transfer of linear force input from the dial 2448 to the switch 2414.

The configuration depicted in FIGS. 24A-B may be used to accept both rotational and translational input from the user. For example, if a user provides a rotational force to the dial 2448, the coupling 2418 and dial 2448 may rotate in the direction of the force. The coupling 2418 may be attached to or integrated with one or more sensors that are configured to detect rotational movement. For example the coupling 2418 may be integrated with an optical encoder, similar to the example described above with respect to FIG. 23. Additionally, if a user provides a translational force to the dial 2448, the force may be transmitted through the dial 2448 and coupling 2418 to actuate the switch 2414. In some cases, the switch 2414 includes a metal dome switch that is configured to provide a tactile feedback when actuated. In some cases,

the actuation of a dome switch may be perceived by the user as a click or release as the switch 2414 is actuated. Once the force has been removed from the dial 2448, the dome switch resiliently returns to its original position, providing a biasing force against the coupling 2418 to return both the dial 2448 and the coupling 2418 to their original positions. In some embodiments, the tactile switch 2414 may include a separate biasing element, such as a spring, that exerts a force (either directly or indirectly via the shear plate) against the coupling. FIG. 24A depicts the tactile switch assembly 2410 when there is no force applied (un-actuated). FIG. 24B depicts the tactile switch assembly 2410 when there is a translational force applied to the dial 2448 (actuated).

11. Example Band Attachment Mechanism

For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above.

As described above, a wearable electronic device may include a band that is attached to a device body having one or more receiving features. In particular, the housing may include or form a receiving feature that facilitates an interchange or replacement of different bands that are used to secure the device to the wrist of the user. By replacing or interchanging bands the device may be adapted for multiple uses ranging from sporting activities to professional or social activities.

In some embodiments, the receiving features are configured to be operated without the use of special tools or fixtures. For example, the bands may be interchanged by hand or with the help of a simple tool, such as a pointed object. Additionally or alternatively, a tool or other component, such as a component of the device to which the attachment system is coupled, may be configured to actuate a button or other component of the attachment system to secure and/or release the band from the device. In one embodiment, the lug portion of a band may be configured to be inserted into an opening or channel portion of the receiving feature. Once the lug of the band has been inserted into the opening, the lug may slide within the opening of the device until the band is secured or otherwise coupled to the device. The coupling between the band and the receiving feature may provide a secure attachment of the band to the housing or device body. Just as the band is configured to slide into the channel of the receiving feature, the lug may also slide out of the channel of the receiving feature allowing the band to be detached from the device body.

In one embodiment, the receiving feature includes a locking mechanism, which may be integrated with portions of either the band or the receiving feature. In one example, as the band is inserted into a receiving feature of the device, the locking mechanism interfaces with a portion of the receiving feature to lock or otherwise secure the band within the receiving feature. The locking mechanism may also be configured to interface with a releasing mechanism associated with the receiving feature. For example, a releasing mechanism may be configured to disengage or release the locking mechanism. In some implementations, actuation of the releasing mechanism causes the locking mechanism to be released and allows the band to be removed by sliding within the receiving feature.

FIG. 25A depicts a receiving feature and band assembly as viewed from the bottom of the device body. As shown in FIG. 25A, a receiving feature 623a includes an opening or channel 2501 that is formed into the body or housing of the



device. The channel 2501 is configured to receive the lug 2510 attached to an end of the band strap 621a. The receiving feature 623a may also include a locking mechanism 2530 that is configured to maintain the band strap 621a within the channel 2501 once it has been installed. As discussed above, the locking mechanism 2530 may be releasable by the user, which may facilitate band replacement. In this example, the locking mechanism 2530 includes a spring-loaded retaining mechanism that engages the lug 2510 to retain the lug 2510 in the channel 2501 and maintain the attachment of the band strap 621a to the device. As shown in FIG. 25A, the locking mechanism 2530 also includes a button located on the bottom of the housing that may be depressed by the user to release the locking mechanism and allow the lug 2510 and the band strap 621a to be removed from the channel 2501. In the present example, the button of the locking mechanism 2530 is located on a curved portion of the case or housing. In some embodiments, the button of the locking mechanism 2530 is located along the centerline of the case or housing.

In some embodiments, the opening or channel 2501 of the receiving feature 623a includes a port or connector for receiving a mating electrical component. In some embodiments, the connector or port is covered by a label or sticker so that the inside surface of the opening or channel 2501 appears continuous. The connector or port may be located along the vertical centerline of the case or housing.

FIG. 25B depicts an example exploded view of the receiving feature 623a and the lug 2510 of the band strap 621a. As shown in FIG. 25B, the band strap 621a may be formed from a separate part and attached to lug 2510 via a pivot or other type of joint. In other embodiments, the band strap 621a may have an end feature that is integrally formed as part of the band strap 621a. As also shown in FIG. 25B, the lug 2510 may be attached to the receiving feature 623a by aligning the axis of the lug 2510 with the axis of the channel 2501 and then sliding the lug 2510 into the channel 2501.

FIG. 25C depicts an example assembly sequence of the lug 2510 being inserted into the channel 2501 of the receiving feature 623a. As shown in FIG. 25C, the lug 2510 may be positioned along the side of the receiving feature 623a having the lug 2510 approximately aligned with the channel 2501 of the receiving feature 623a. The lug 2510 (and band strap 621a) may then be inserted into the channel 2501 of the receiving feature 623a by sliding the lug 2510 along the length of the channel 2501. Once the lug 2510 is approximately centered in the channel 2501 of the receiving feature 623a, the locking mechanism 2530 or other securing feature may engage, thereby retaining the lug 2510 (and band strap 621a) within the channel 2501. As previously discussed, the lug 2510 (and band strap 621a) may be removed from the receiving feature 623a by depressing the button of the locking mechanism 2530, which may disengage the lock and allow movement of the lug 2510 within the channel 2501.

The example described above is provided with respect to one example embodiment. The geometry of the end of the band strap and/or the geometry of the channel may vary depending on the implementation. Additionally, the engagement mechanism may vary depending on the design of the band strap and the device body. The geometry or layout of the features may vary and remain within the scope of the present disclosure. Additionally, while the examples provided above are described with respect to attaching a band strap to a device body, the receiving feature (623a) may be used to attach a variety of other parts to the device body. For

example a lanyard, cable, or other accessory may be attached to the device body using the receiving feature and other similar features.

12. Example Bands

As described above, a wearable electronic device may include a band that is used to secure the device to the wrist of a user. In some embodiments, the band may be formed from two band straps that are attached to the housing of the device body. The band straps may be secured around the wrist of a user by a clasp or latching mechanism. As also described above, the device may be configured to facilitate replacement of the band. This feature may allow the use of a variety of types of bands, which may adapt the device for multiple uses ranging from sporting activities to professional or social activities.

In some cases, the band may be formed from a woven textile material. In one example, the band is formed from a woven material that includes one or more strands or threads formed from a natural or synthetic material. The woven material may be formed, for example, from a plurality of warp threads that are woven around one or more weft threads. More specifically, the woven material may include a plurality of warp threads disposed along the length of the band, and at least one weft thread positioned perpendicular to, and coupled to, woven or interlaced between the plurality of warp threads. In some cases, the plurality of warp threads may run the entire length of the woven portion of the band strap. Additionally, in some cases, the at least one weft thread may include a single thread that may be continuously woven between the plurality of warp threads or, alternatively, may include a plurality of threads that may be woven between the plurality of warp threads. A weft thread that is woven between a plurality of warp threads may form consecutive cross-layers with respect to the plurality warp threads in order to form the band.

In some cases, one or more of the strands or threads may be a metallic or conductive material. This may improve the strength of the band and may also facilitate coupling with magnetic elements, such as a metallic clasp. In some cases, other elements may be woven into the band, including, for example, product identifying elements, decorative elements, or functional components.

In other embodiments, the band may be formed from a metallic mesh material. In one example, the metallic mesh is formed from an array of links that are interlocked to form a sheet of fabric. Some or all of the links in the mesh may be formed from a ferromagnetic material, which may facilitate magnetic engagement with a magnetic clasp. In some cases, each link of the mesh is formed from a section of metallic filament that is bent or formed into a closed shape. Each closed shape may be interlocked with one or more adjacent links to form a portion of the sheet or fabric. In some cases, a metallic filament is formed around a series of rods or pins that are disposed at a regular spacing within the mesh. In some cases, one or more strands or filaments that may be formed from a ferromagnetic material are woven or integrated with the links of the mesh.

In other examples, the band may be formed from a sheet of material. For example, the band may be formed from a synthetic leather, leather, or other animal hide. Additionally or alternatively, the band may be formed from a polymer material, an elastomer material, or other type of plastic or synthetic. In some cases, the band is formed from a silicone sheet material.

The clasp that is used to attach the free ends of the band straps may vary depending on the material that is used and the construction of the band. For example, as mentioned

above, a metallic mesh material may use a metallic clasp to join the ends of the band. Additionally, a leather band may be integrated with magnetic and/or ferromagnetic components and may include a magnetic clasp. In some embodiments, the free ends of the band straps are secured using a buckle or tang on a first band strap that is configured to interface with a hole or aperture in a second band strap. A variety of other clasp configurations may also be used.

13. Example Display

For the purposes of the following description, the described device 100 is one example of that shown and discussed above with respect to FIGS. 2-7. However, certain features of the device 100, including the external surface geometry, may be simplified or vary with respect to aspects of the device 100 discussed above. As described above, the device includes a display disposed within the housing or enclosure. The device may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user, including, for example, a graphical user interface, notifications, health statistics, and the like. In some cases, the display may be configured to present the current time and date similar to a traditional watch or timepiece.

In some embodiments, the display is formed from an organic light emitting diode (OLED) display element. An active region of the display may include an array of light-emitting display pixels 2604 such as array 2602, shown in FIG. 26. Pixels 2604 may be arranged in rows and columns in array 2602 and may be controlled using a pattern of control lines. Each pixel may include a light-emitting element such as organic light-emitting diode 2612 and associated control circuitry 2610. Control circuitry 2610 may be coupled to the data lines 2606 and gate lines 2608 so that control signals may be received from driver circuitry, which may be implemented as an integrated circuit. Although described as an OLED display, certain embodiments may implement other display technology, such as LCD displays and the like.

To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device 100, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device 100 may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

Although the disclosure above is described in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments but instead defined by the claims herein presented.

We claim:

1. An electronic watch comprising:  
a housing formed from a metal material and defining a rear opening along a rear portion of the housing;

- a touch-sensitive display positioned at least partially within the housing;
- a band coupled to the housing and configured to couple the electronic watch to a user;
- a cover formed from a dielectric material and forming a seal along the rear opening of the housing;
- an optical sensor positioned within the housing and configured to transmit an optical signal through the dielectric material of the cover;
- a charging coil positioned within the housing and configured to receive wireless power through the dielectric material of the cover;
- a first electrode positioned along a rear surface of the electronic watch; and
- a second electrode positioned along the rear surface of the electronic watch, wherein:
  - the electronic watch is configured to measure a heart rate using the optical sensor, and
  - the electronic watch is configured to measure an electrocardiogram using the first electrode and the second electrode.
2. The electronic watch of claim 1, wherein:
  - the cover defines at least one window for the optical sensor; and
  - the cover protrudes outward from a rear housing surface of the housing.
3. The electronic watch of claim 1, wherein:
  - the cover is formed from a transparent substrate; and
  - the transparent substrate comprises one or more of a glass or a sapphire material.
4. The electronic watch of claim 1, wherein:
  - the electronic watch further comprises a first magnet positioned within the housing;
  - the first magnet is configured to couple to a second magnet positioned within a charging dock; and
  - the first and second magnets are configured to maintain alignment of the electronic watch with respect to the charging dock.
5. The electronic watch of claim 1, wherein:
  - the electronic watch further comprises a near-field communication system; and
  - the near-field communication system is configured to transmit signals through one or more of the housing or the cover.
6. The electronic watch of claim 1, wherein:
  - the cover defines a convex exterior profile; and
  - the convex exterior profile facilitates alignment between the cover and a mating surface of an external wireless charging device.
7. A wearable electronic device comprising:
  - a housing formed from a conductive material and defining a first opening opposite to a second opening;
  - a band attached to the housing and configured to secure the wearable electronic device to a user;
  - a display positioned in the first opening;
  - a cover comprising a non-conductive material and positioned over the second opening, the cover forming a portion of an exterior surface of the wearable electronic device;
  - a biosensor module positioned below the cover configured to pass an optical signal through a window defined within the non-conductive material of the cover; and
  - a wireless charging receive coil aligned with the second opening and below the cover, the wireless charging receive coil configured to inductively couple to an external wireless charging device through the non-conductive material of the cover.

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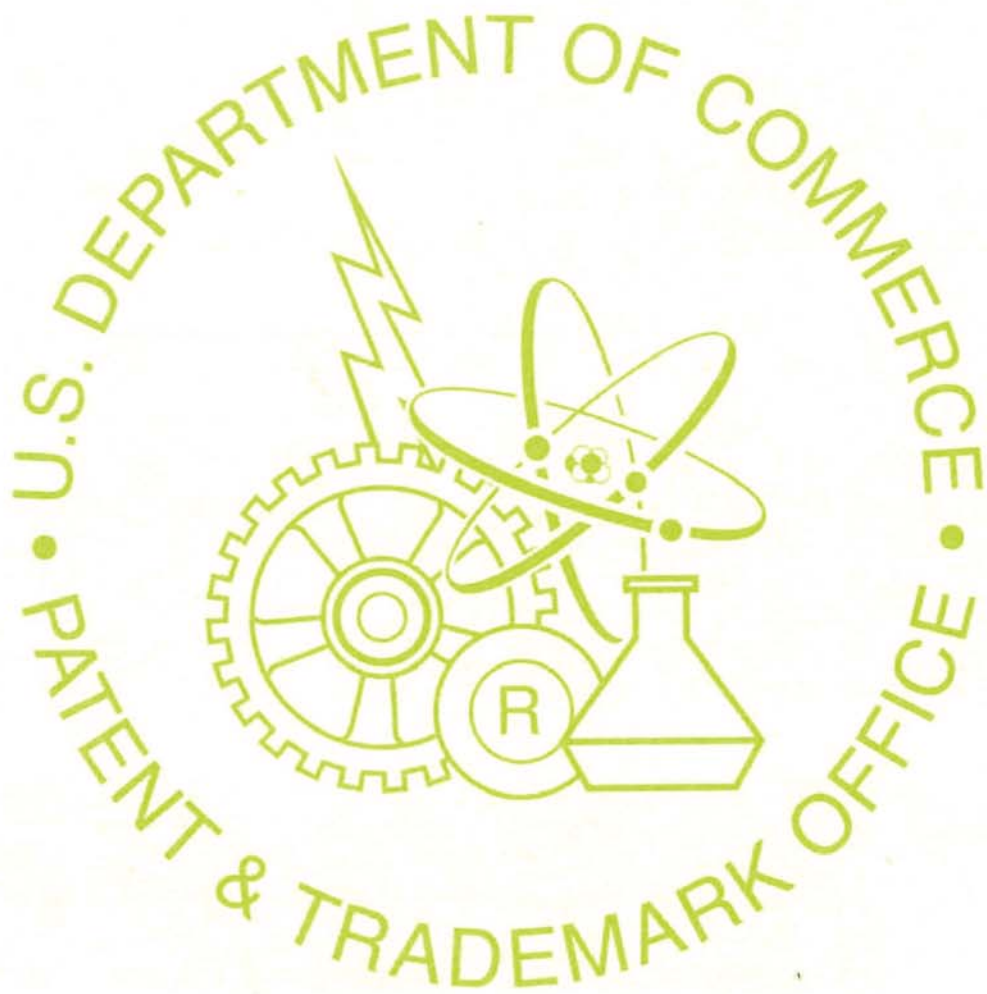
8. The wearable electronic device of claim 7, wherein:  
the window is a first window;  
the cover defines a second window; and  
the biosensor module comprises:  
a light source configured to emit light toward a region 5  
of skin of the user through the first window; and  
a detector configured to receive light reflected from the  
region of the skin through the second window.  
9. The wearable electronic device of claim 7, wherein: 10  
the biosensor module comprises:  
at least one light source; and  
a set of detectors; and  
the at least one light source and the set of detectors are  
configured to operate as a photoplethysmogram (PPG) 15  
sensor.  
10. The wearable electronic device of claim 7, wherein:  
the cover protrudes outward from a rear surface of the  
housing;  
the cover defines a convex exterior profile; and  
the convex exterior profile facilitates alignment between 20  
the cover and a mating surface of the external wireless  
charging device.  
11. The wearable electronic device of claim 10, wherein:  
the cover forms a waterproof seal with the housing along 25  
a perimeter of the cover.  
12. The wearable electronic device of claim 7, wherein:  
the wearable electronic device further comprises a first  
magnet positioned within the housing and below the  
cover; 30  
the external wireless charging device comprises a second  
magnet; and  
the first and second magnets are configured to maintain  
alignment between the wearable electronic device and  
the external wireless charging device during a charging 35  
operation.  
13. The wearable electronic device of claim 7, wherein:  
the wearable electronic device further comprises:  
a first electrode positioned along a rear surface of the  
wearable electronic device; and  
a second electrode positioned along the rear surface of 40  
the wearable electronic device; and  
the wearable electronic device is configured to measure an  
electrocardiographic characteristic using the first and  
second electrodes. 45  
14. An electronic device comprising:  
a housing defining a first opening and a second opening;  
a display positioned at least partially within the first  
opening;  
a biosensor module aligned with the second opening;

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a wireless charging receive coil positioned within the  
housing and aligned with the second opening;  
a battery operably coupled to the wireless charging  
receive coil; and  
a cover formed from an optically transparent material and  
disposed over the biosensor module and the wireless  
charging receive coil, wherein:  
the electronic device is configured to receive wireless  
power through the optically transparent material of  
the cover using the wireless charging receive coil;  
and  
the electronic device is configured to measure a heart  
rate of a user through the optically transparent mate-  
rial of the cover using the biosensor module.  
15. The electronic device of claim 14, wherein:  
the biosensor module includes an array of optical com-  
ponents; and  
the cover defines an array of windows, each window of  
the array of windows aligned with a respective optical  
component of the array of optical components.  
16. The electronic device of claim 14, wherein:  
the biosensor module comprises:  
a light source; and  
a detector;  
the light source and the detector are configured to measure  
changes in light absorption by a region of skin of the  
user;  
the electronic device is configured to compute the heart  
rate using the measured changes in light absorption;  
and  
the display is configured to display information associated  
with the heart rate.  
17. The electronic device of claim 14, wherein:  
the electronic device further comprises:  
a first electrode disposed along an exterior of the  
electronic device; and  
a second electrode disposed along the exterior of the  
electronic device; and  
the first and second electrodes are configured to measure  
an electrocardiographic characteristic of the user.  
18. The electronic device of claim 14, wherein:  
the electronic device further comprises a magnet that is  
configured to magnetically couple the electronic device  
to an external inductive power transmitter dock through  
the cover.  
19. The electronic device of claim 14, wherein the cover  
protrudes outward from a rear surface of the housing to  
facilitate alignment between the cover and a mating surface  
of an external wireless charging device.

\* \* \* \* \*





# EXHIBIT 8



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# THE UNITED STATES OF AMERICA

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**UNITED STATES DEPARTMENT OF COMMERCE**

**United States Patent and Trademark Office**

January 26, 2023

**THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM  
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**PATENT NUMBER: 10,987,054**

**ISSUE DATE: April 27, 2021**

By Authority of the  
Under Secretary of Commerce for Intellectual Property  
and Director of the United States Patent and Trademark Office

*W. Montgomery*  
Wanda Montgomery  
Certifying Officer





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(12) **United States Patent**  
**Pandya et al.**

(10) **Patent No.:** **US 10,987,054 B2**  
(45) **Date of Patent:** **\*Apr. 27, 2021**

(54) **WEARABLE ELECTRONIC DEVICE WITH ELECTRODES FOR SENSING BIOLOGICAL PARAMETERS**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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**A61B 5/0404** (2006.01)  
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(Continued)

(58) **Field of Classification Search**  
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See application file for complete search history.

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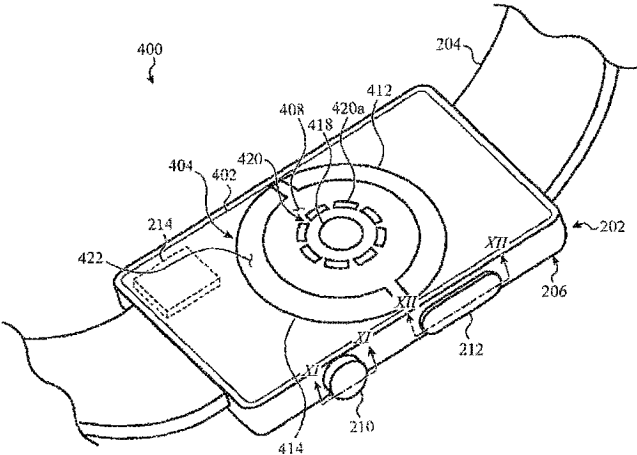
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(57) **ABSTRACT**

An electronic device, such as a watch, has a housing to which a carrier is attached. The carrier has a first surface interior to the electronic device, and a second surface exterior to the electronic device. A set of electrodes is deposited on the exterior surface of the carrier. An additional electrode is operable to be contacted by a finger of a user of the electronic device while the first electrode is positioned

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against skin of the user. The additional electrode may be positioned on a user-rotatable crown of the electronic device, on a button of the electronic device, or on another surface of the housing of the electronic device. A processor of the electronic device is operable to determine a biological parameter of the user based on voltages at the electrodes. The biological parameter may be an electrocardiogram.

20 Claims, 41 Drawing Sheets

Related U.S. Application Data

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*A61B 5/024* (2006.01)  
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*G04G 9/00* (2006.01)  
*G04G 21/02* (2010.01)  
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CPC ..... *A61B 5/044* (2013.01); *A61B 5/0404* (2013.01); *A61B 5/04085* (2013.01); *G04G 9/0005* (2013.01); *G04G 21/025* (2013.01); *G04G 21/08* (2013.01); *G06F 1/163* (2013.01)

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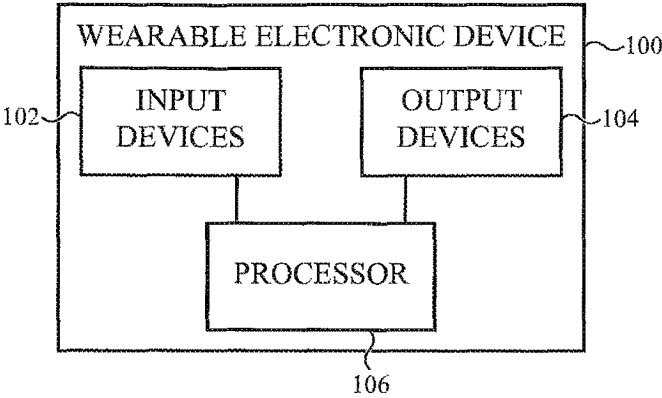


FIG. 1A

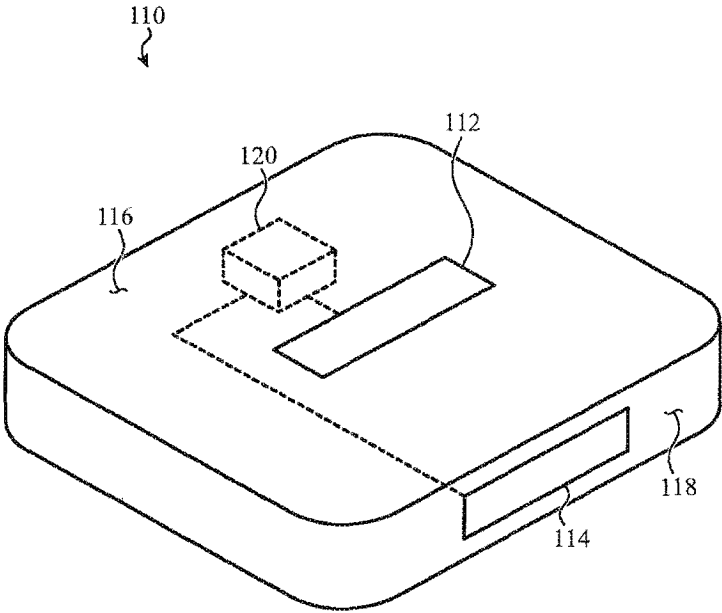


FIG. 1B

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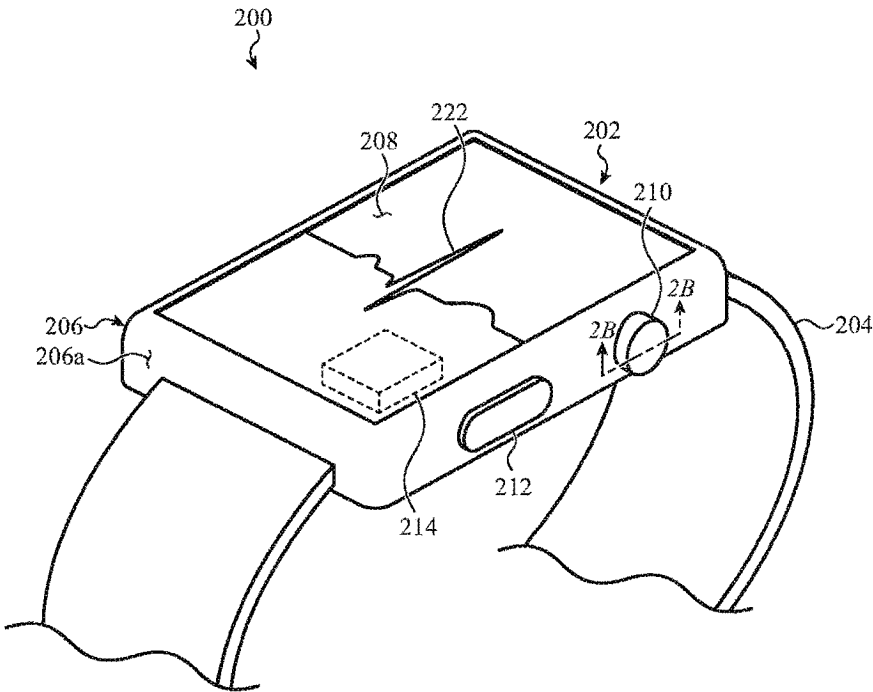


FIG. 2A





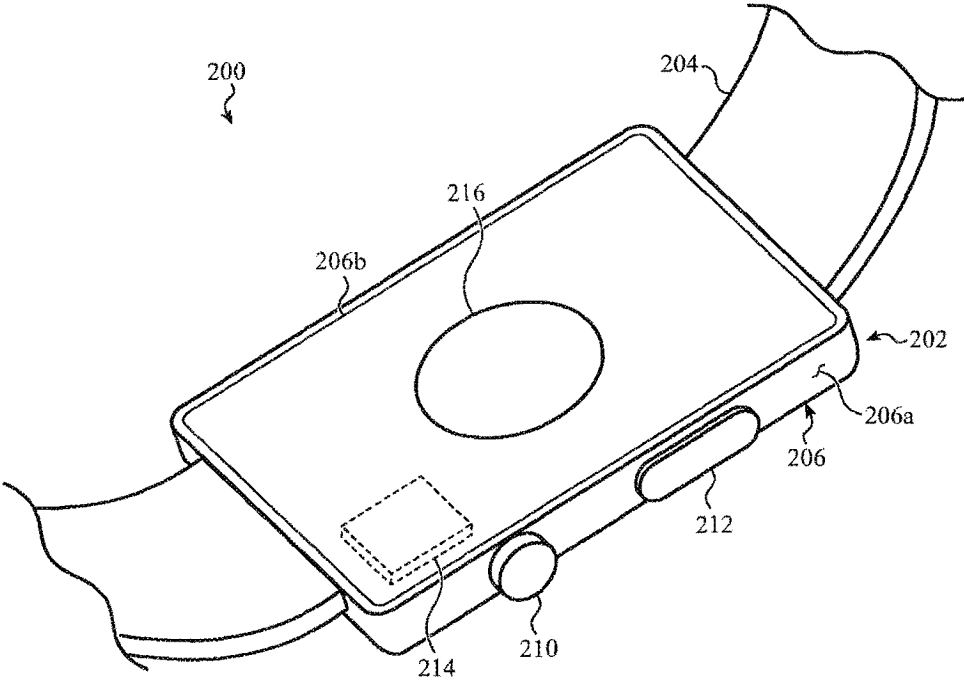


FIG. 2C

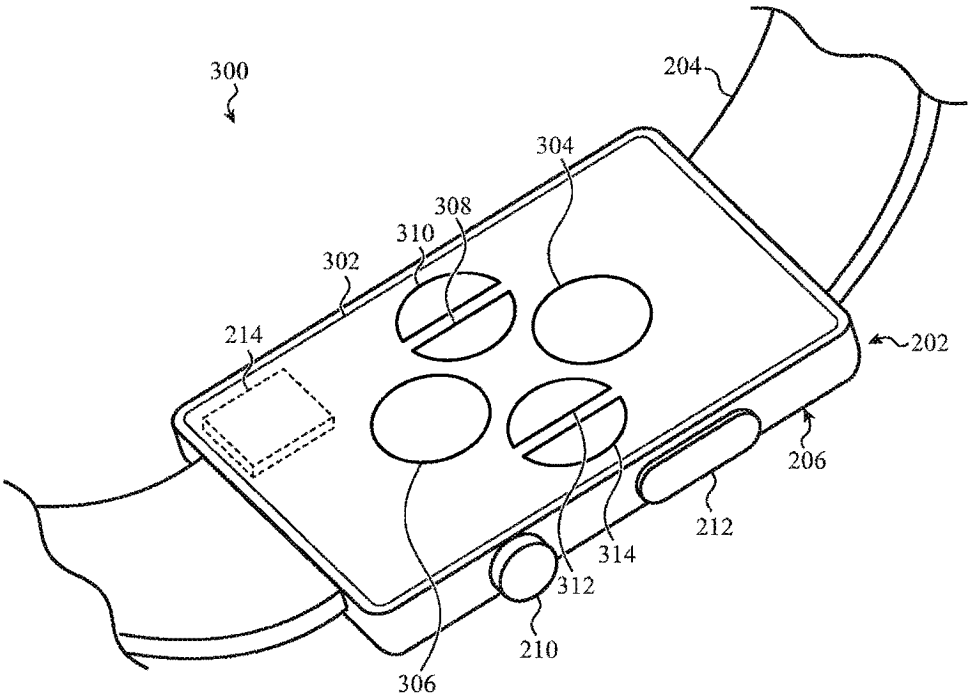


FIG. 3

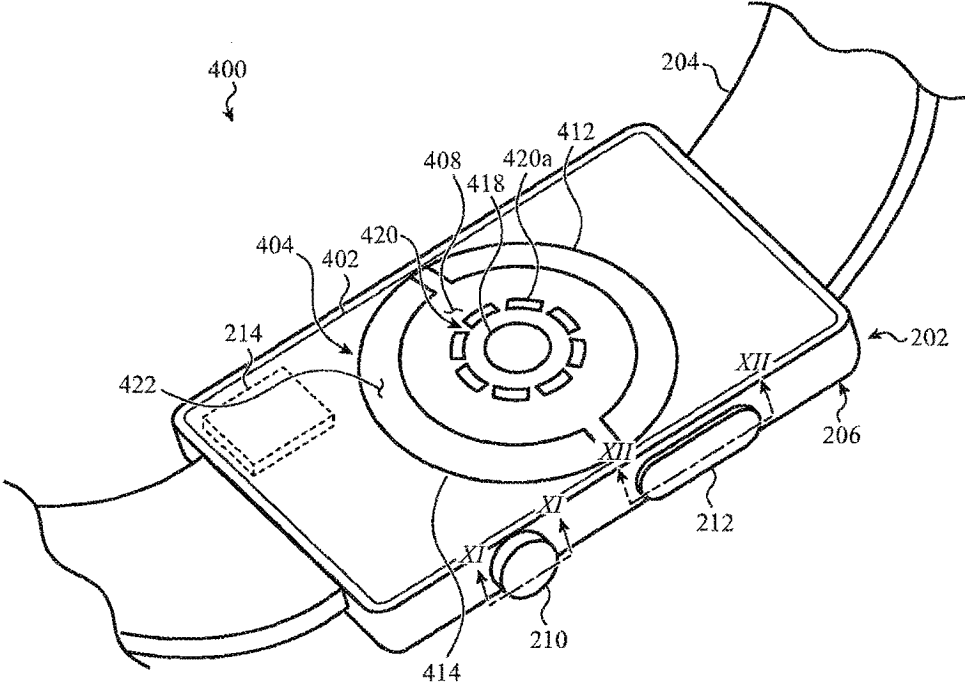


FIG. 4A

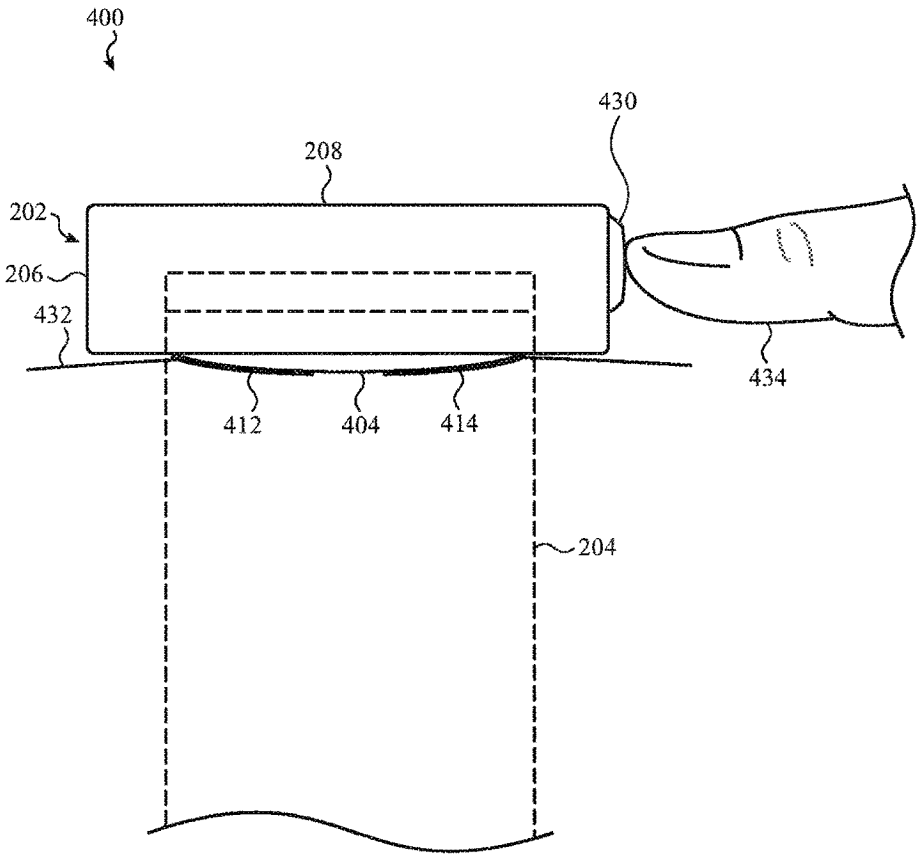


FIG. 4B



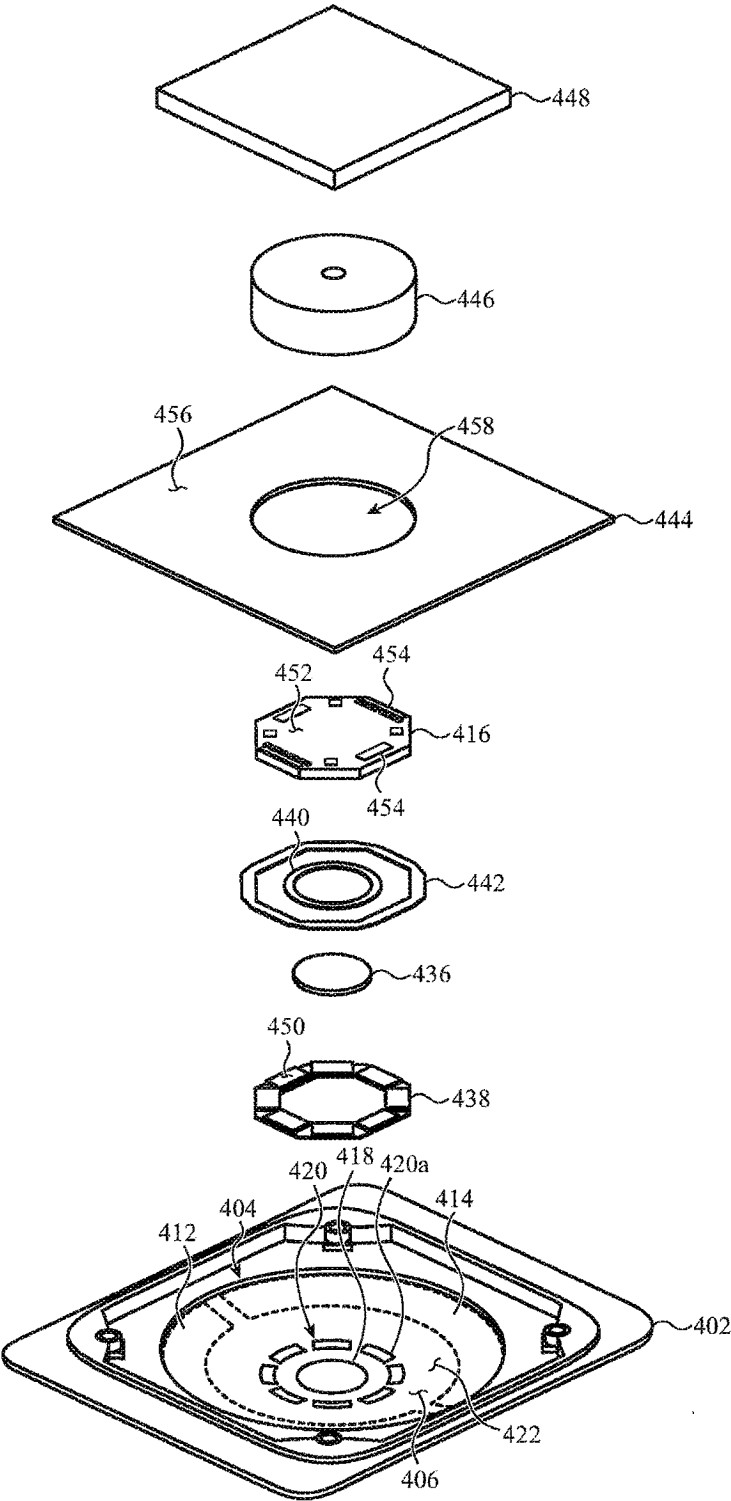


FIG. 4C

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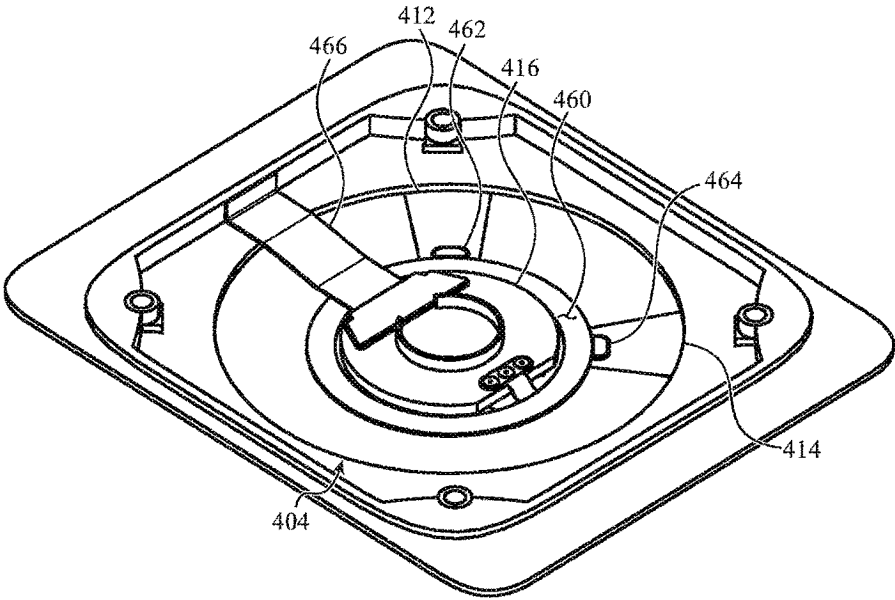


FIG. 4D

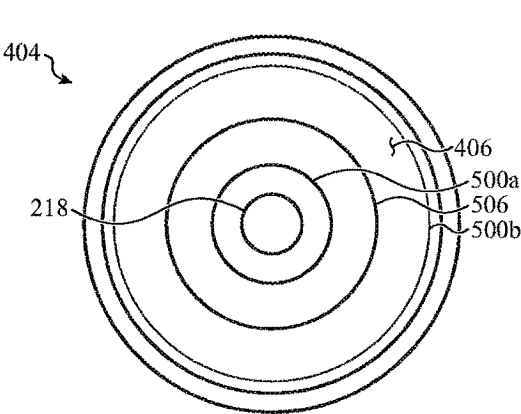


FIG. 5A

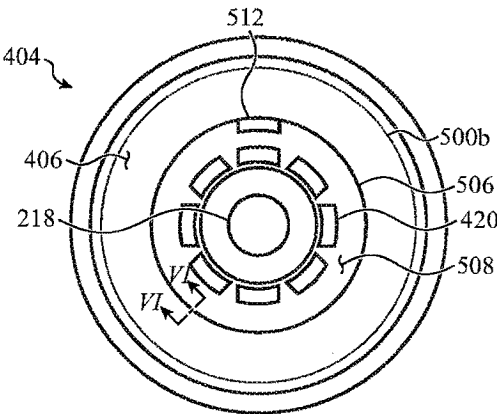


FIG. 5B

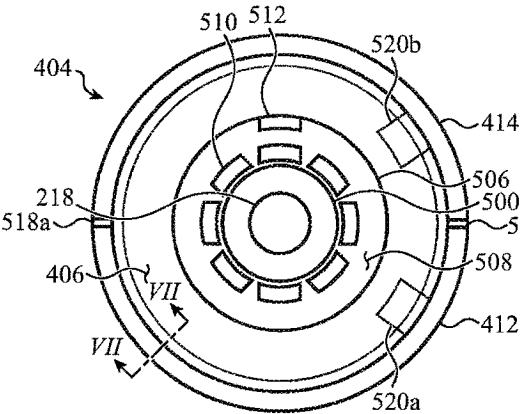


FIG. 5C

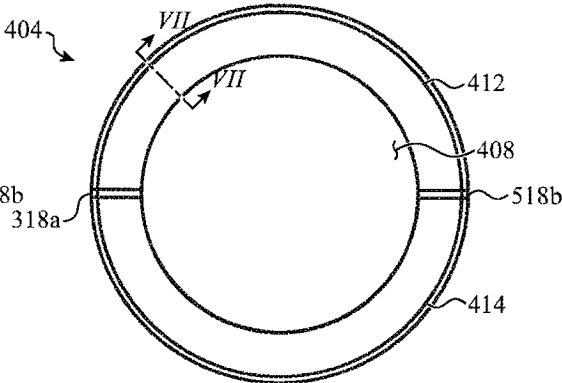


FIG. 5D

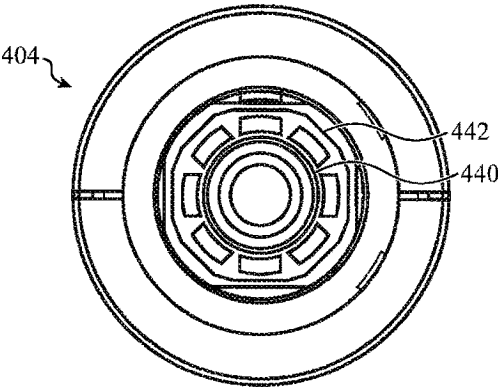


FIG. 5E

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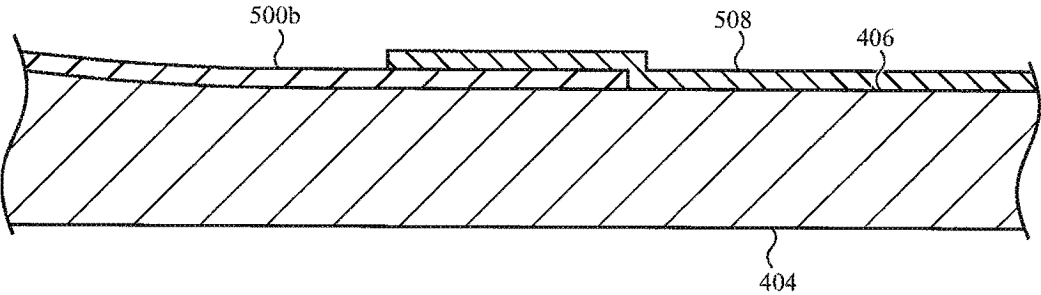


FIG. 6

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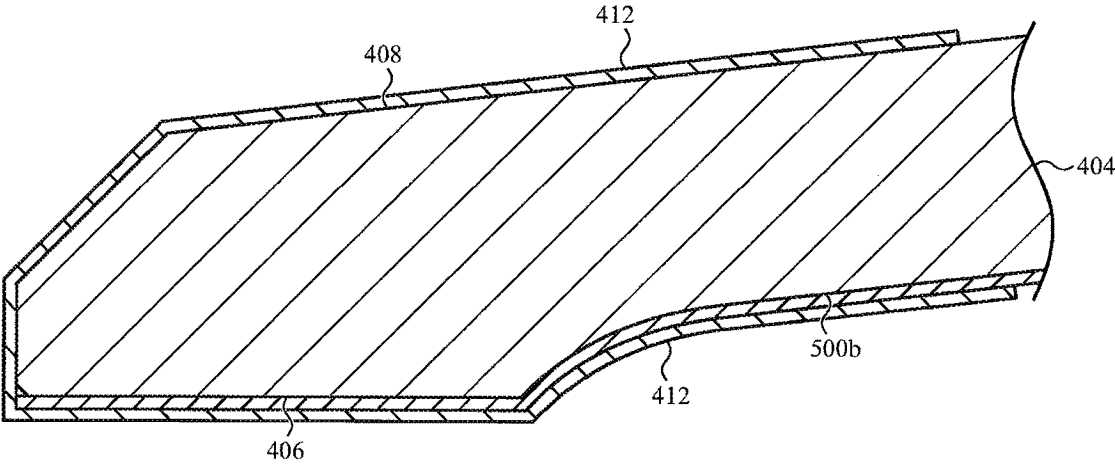


FIG. 7



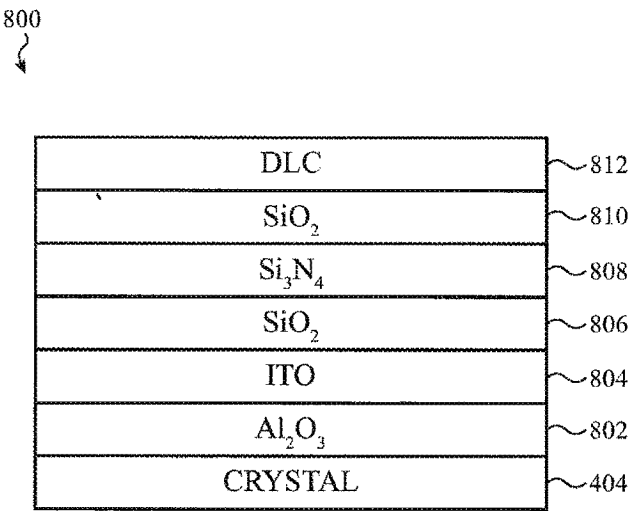


FIG. 8

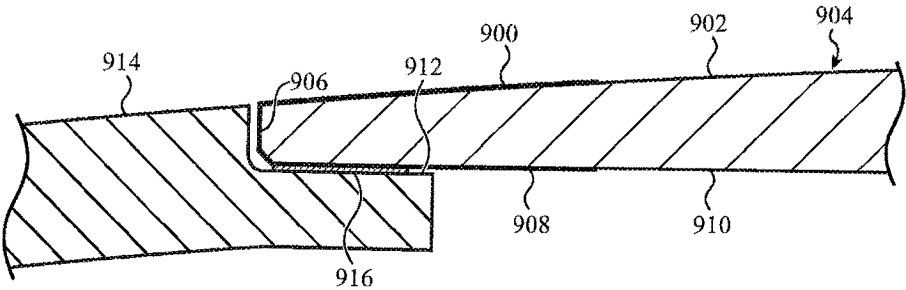


FIG. 9A

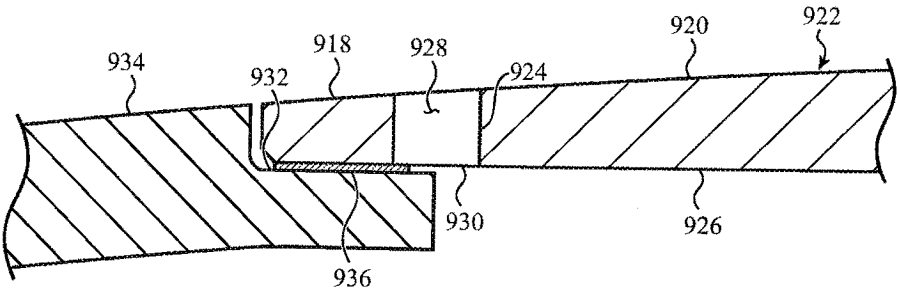


FIG. 9B

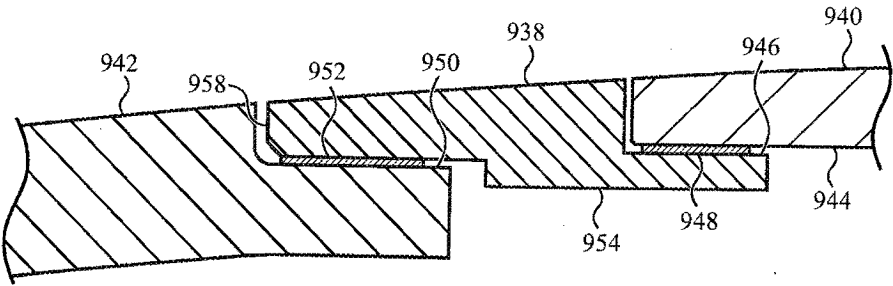


FIG. 9C

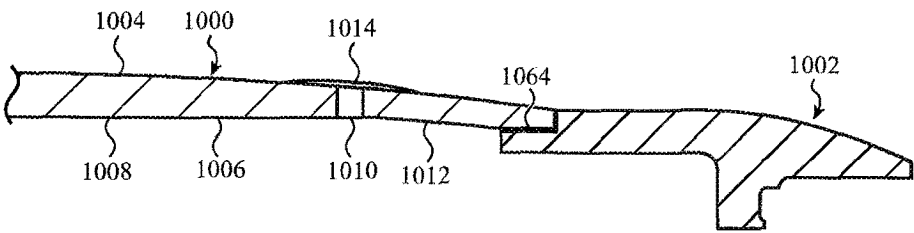


FIG. 10A

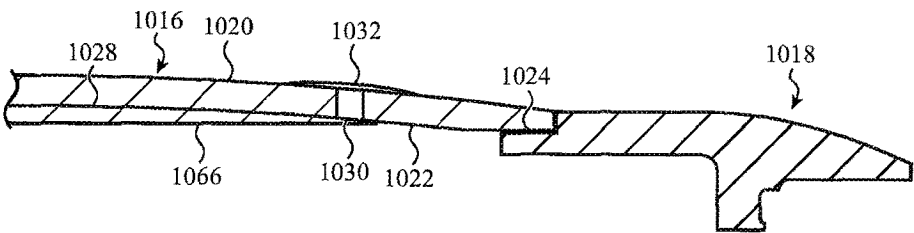


FIG. 10B

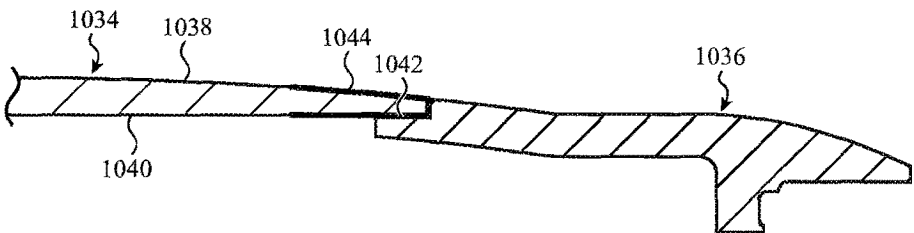


FIG. 10C

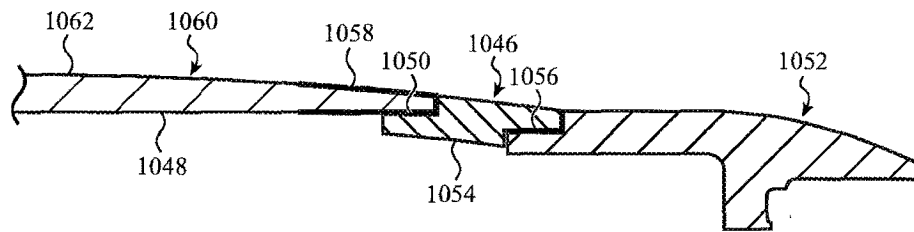


FIG. 10D

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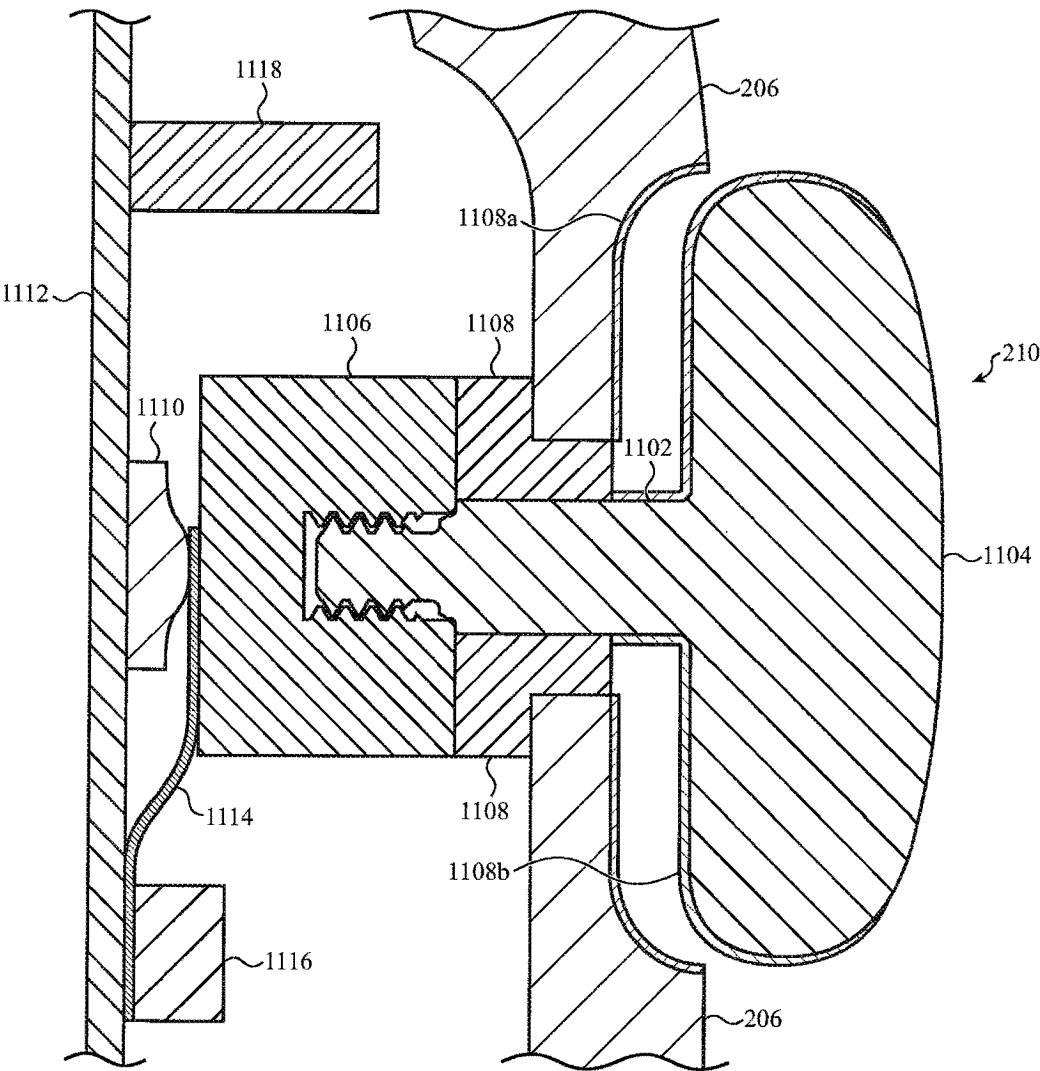


FIG. 11A

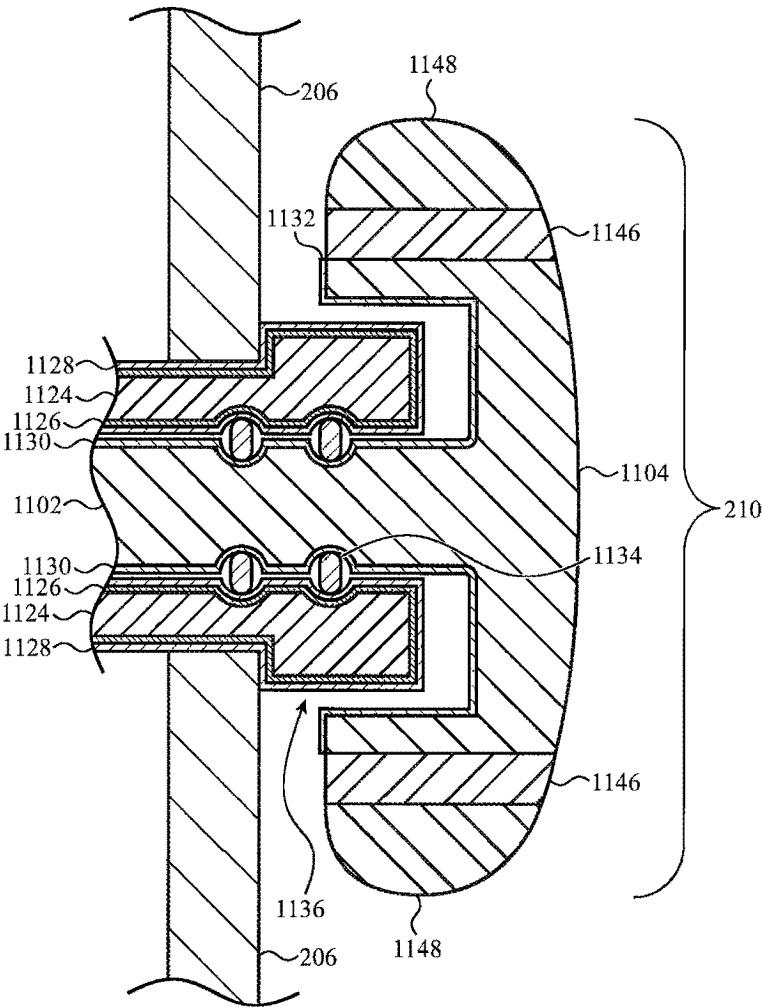


FIG. 11B



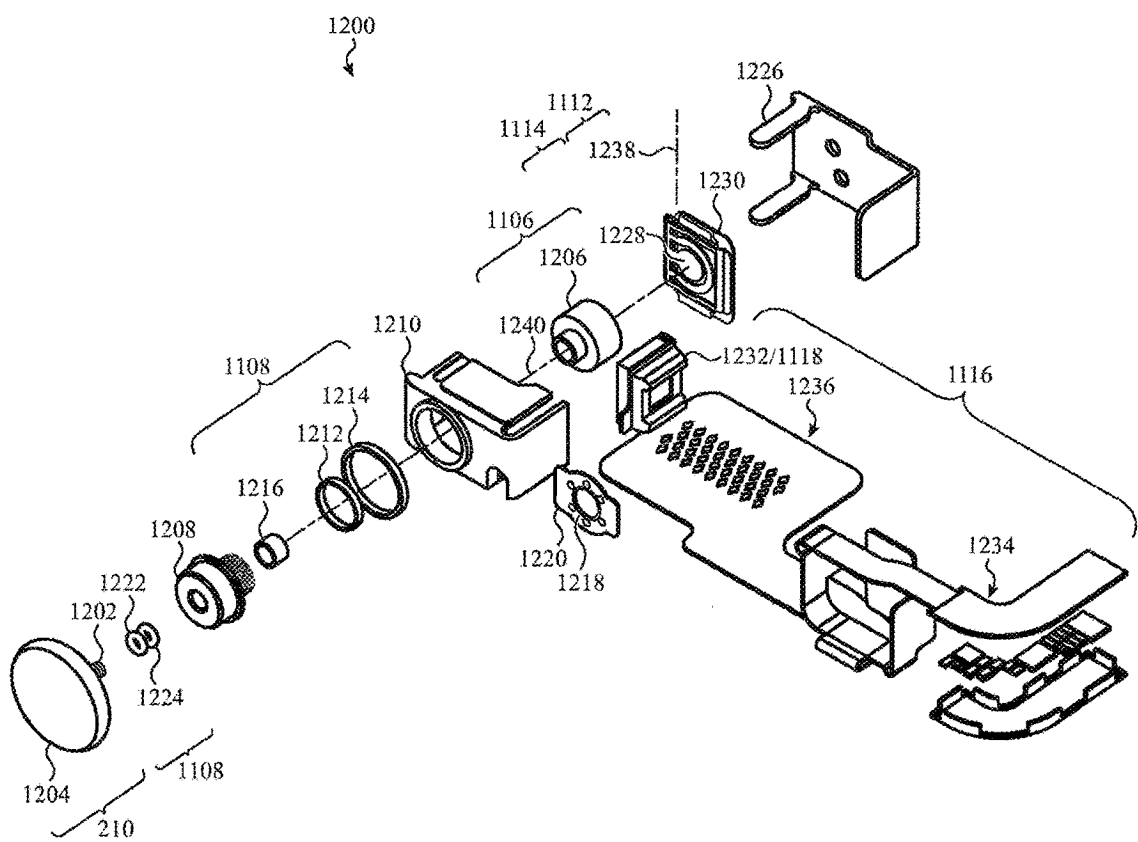


FIG. 12A

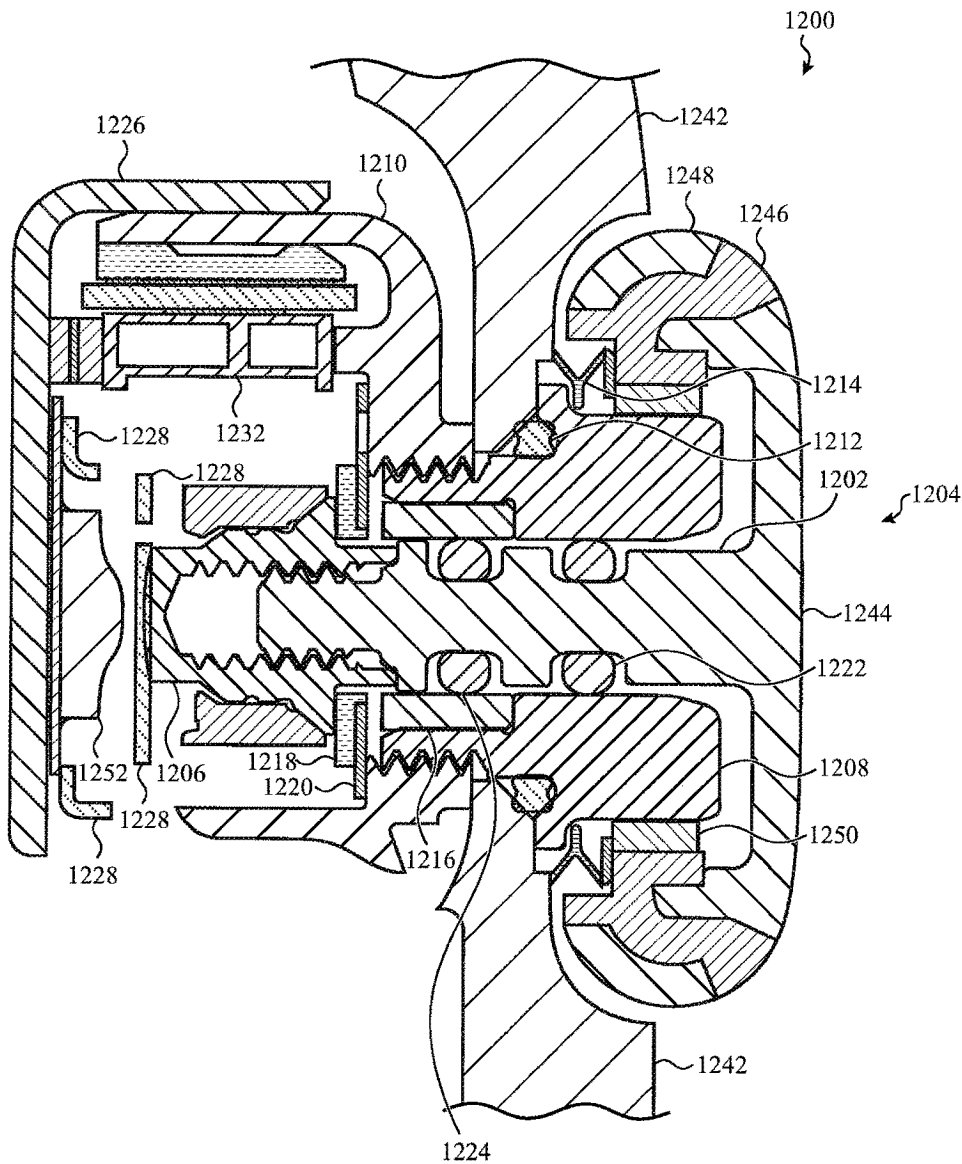


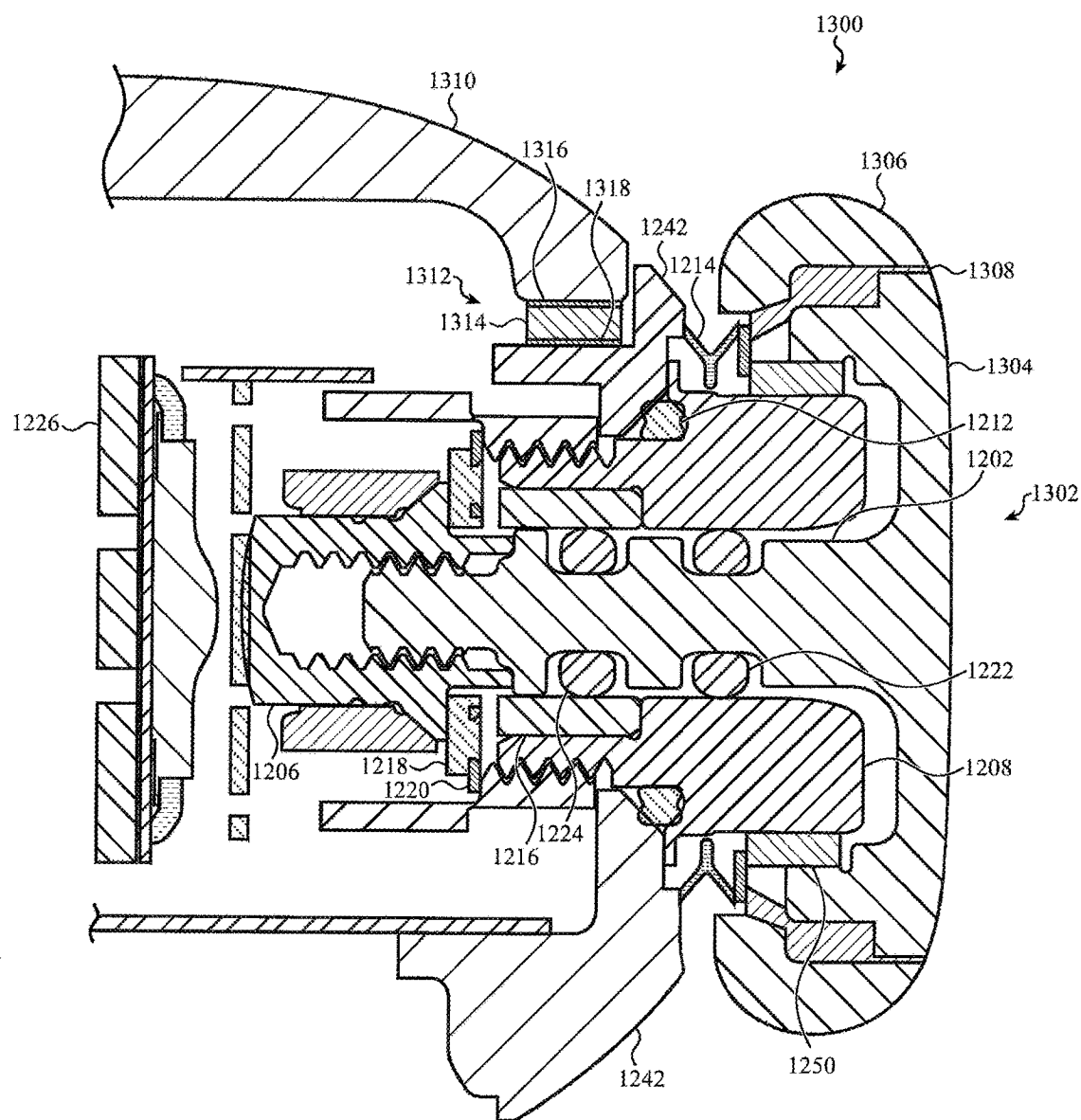
FIG. 12B

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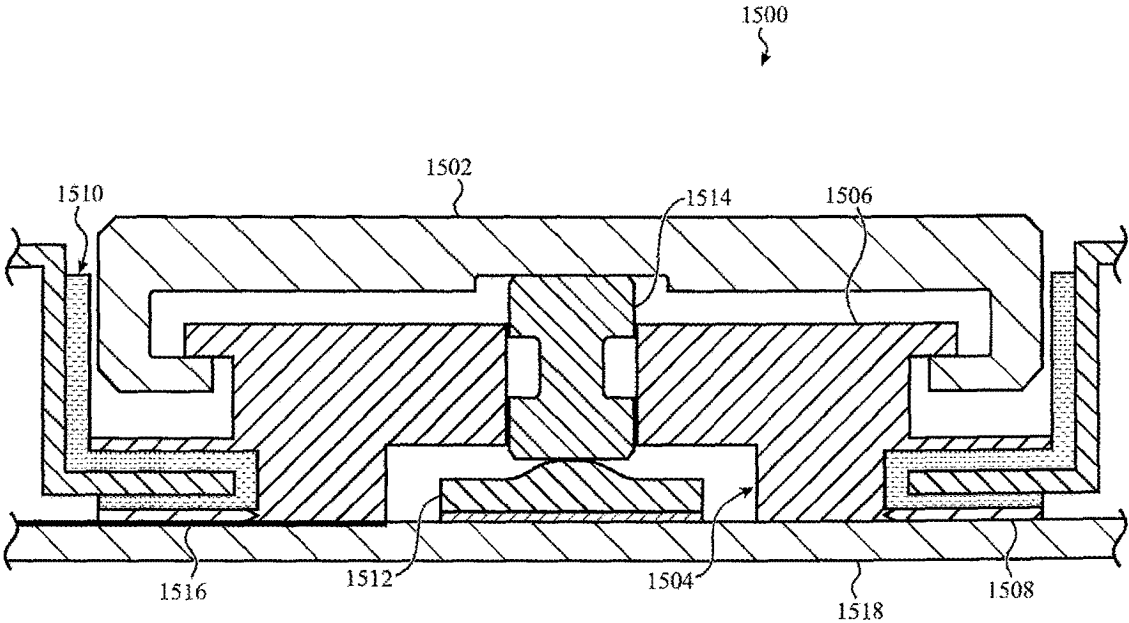


FIG. 15



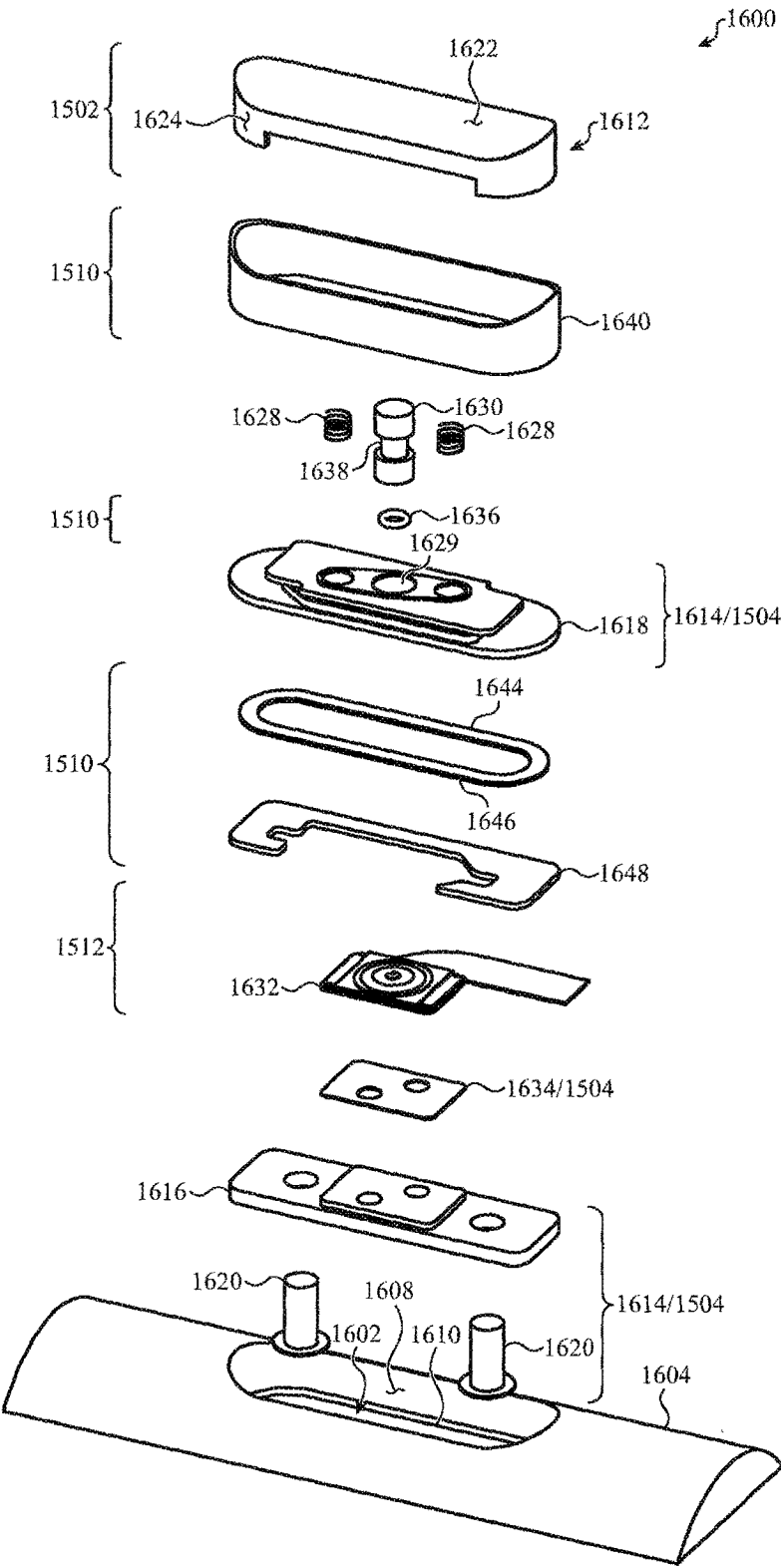


FIG. 16A

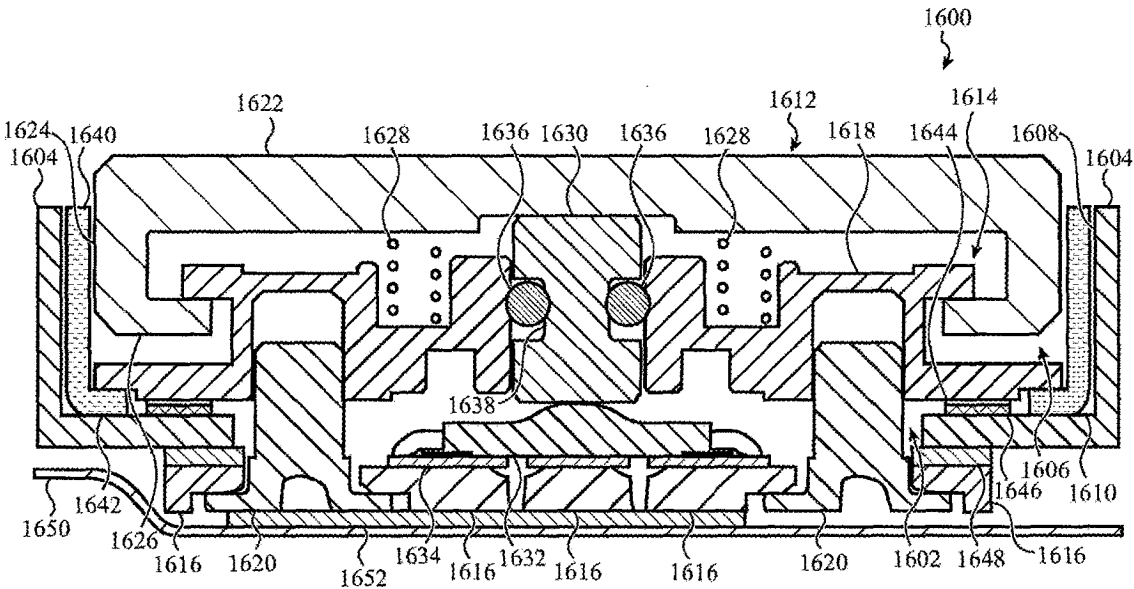


FIG. 16B

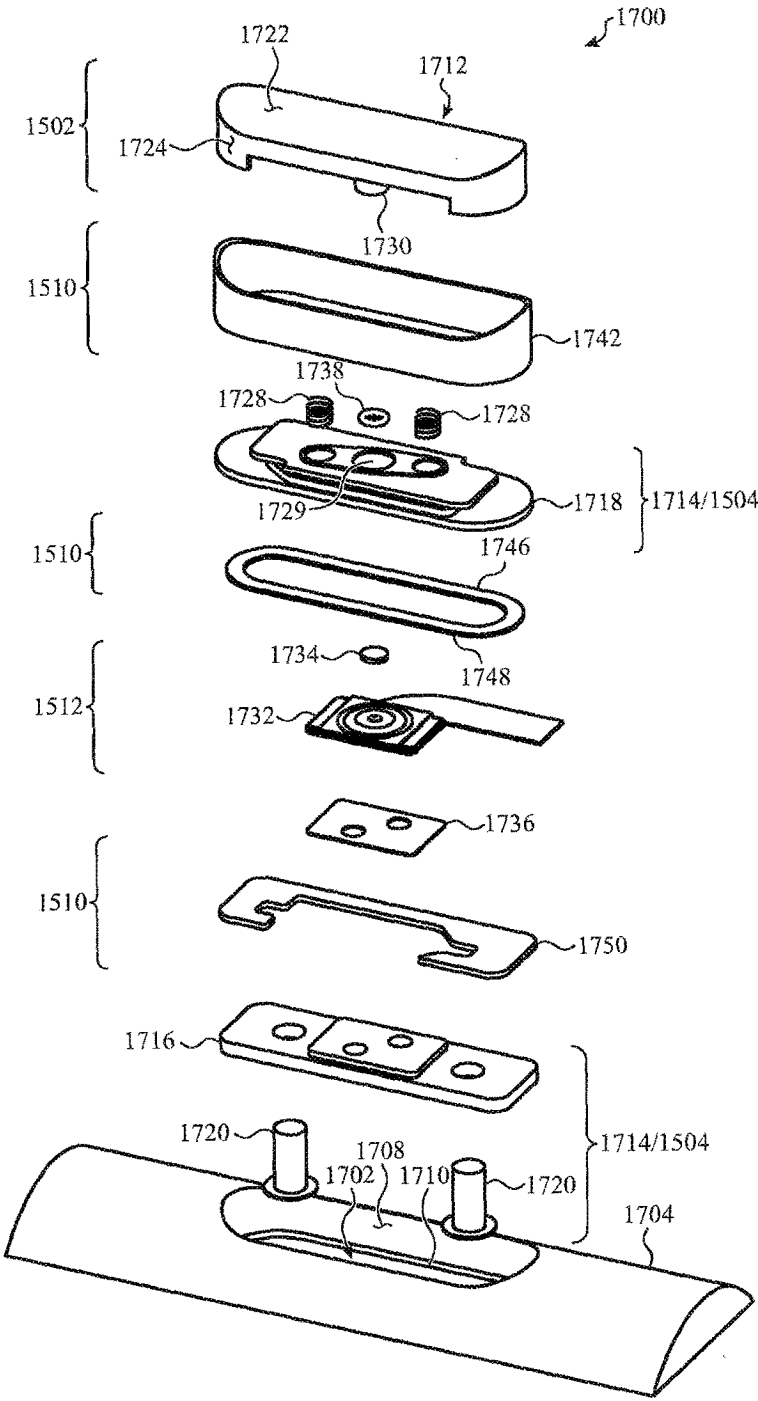


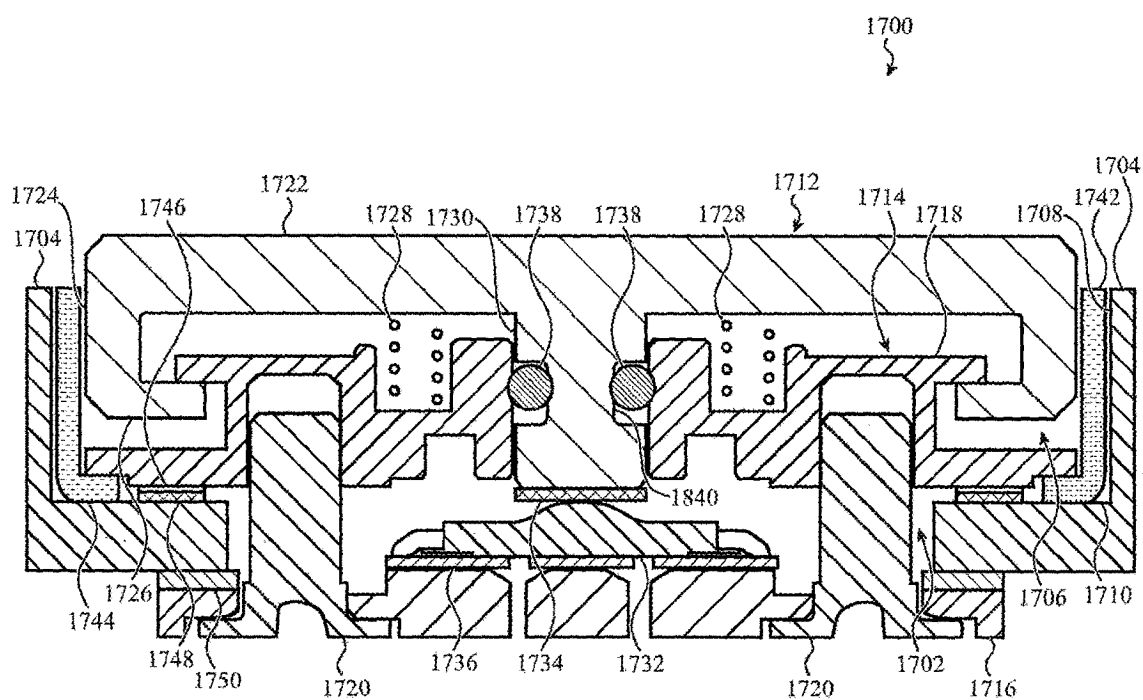
FIG. 17A

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**FIG. 17B**

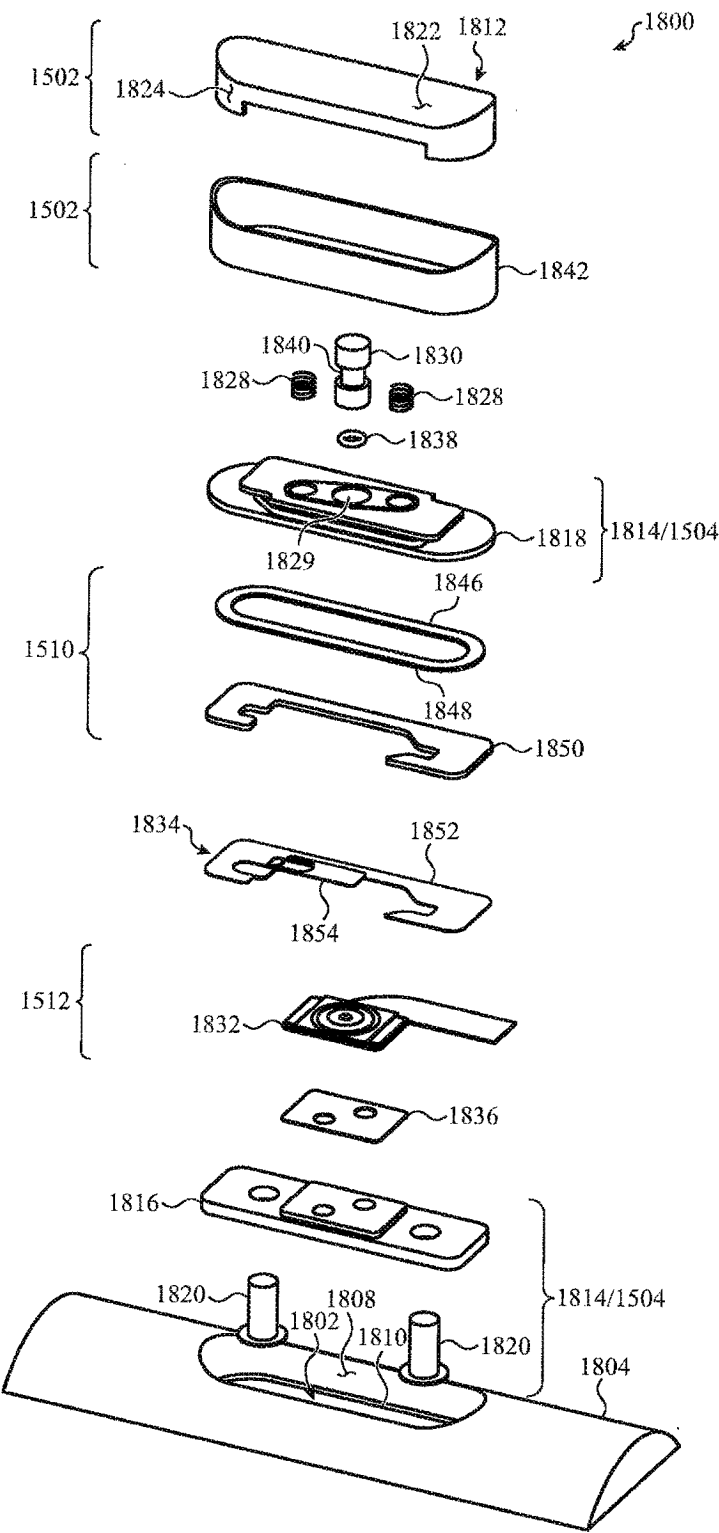


FIG. 18A

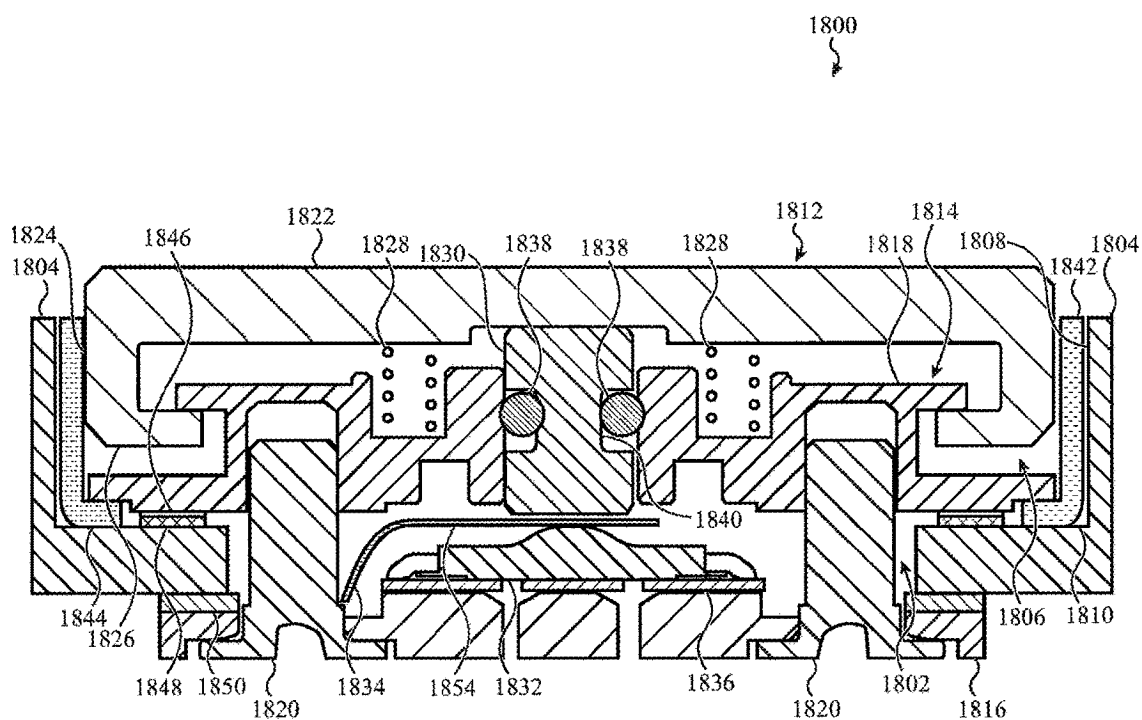


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**FIG. 18B**

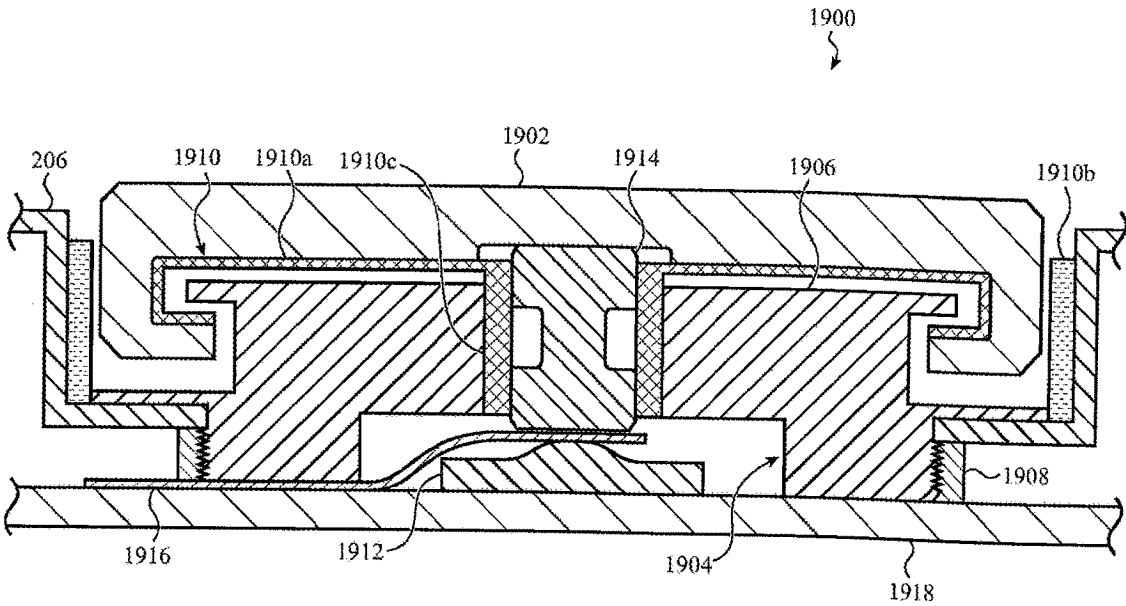


FIG. 19

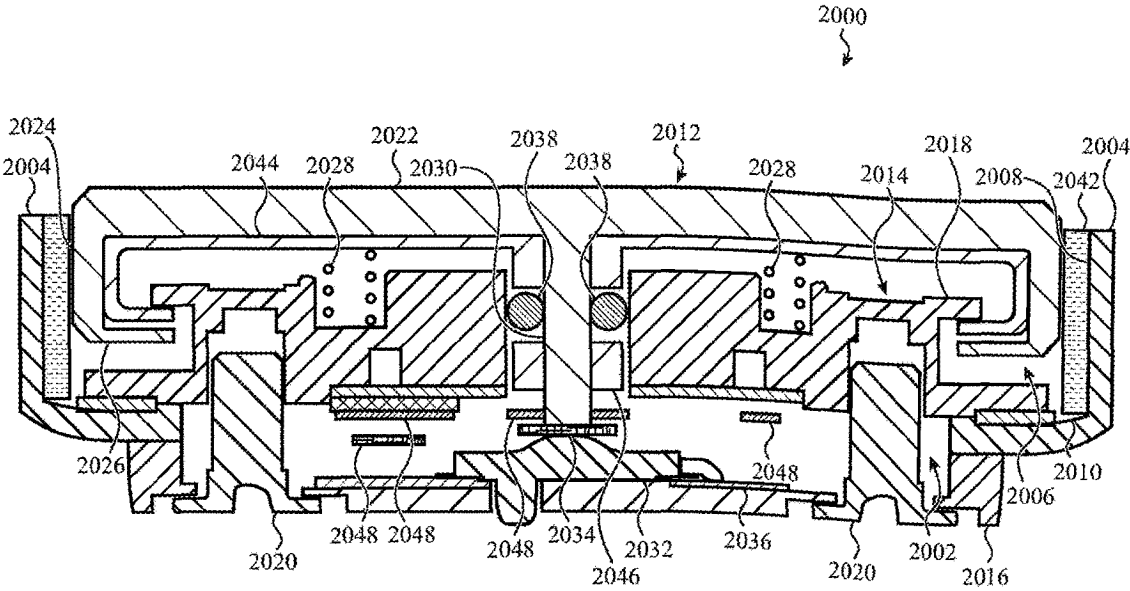


FIG. 20

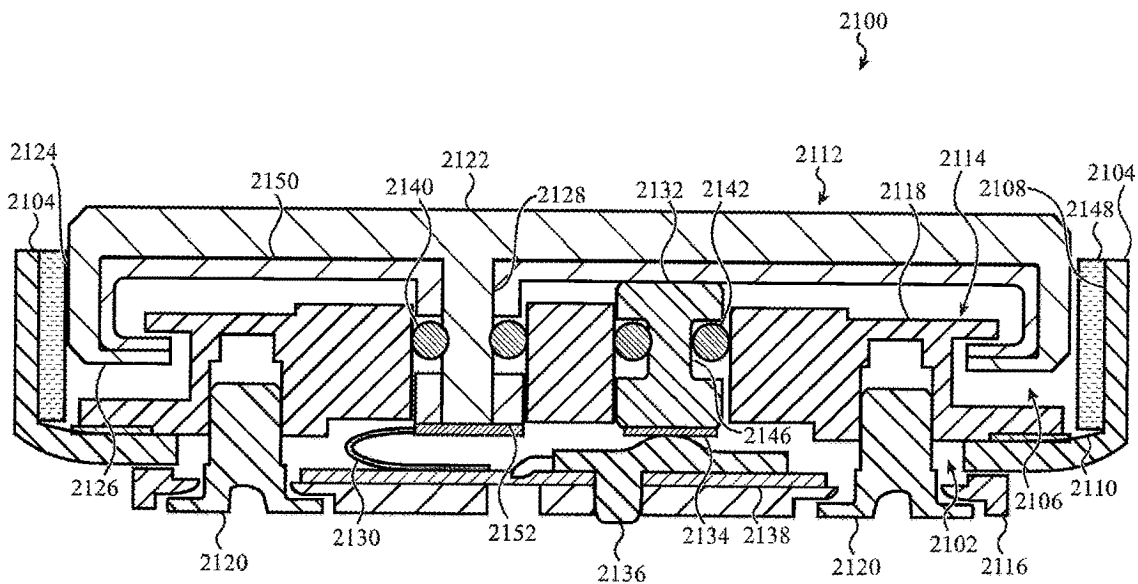


FIG. 21

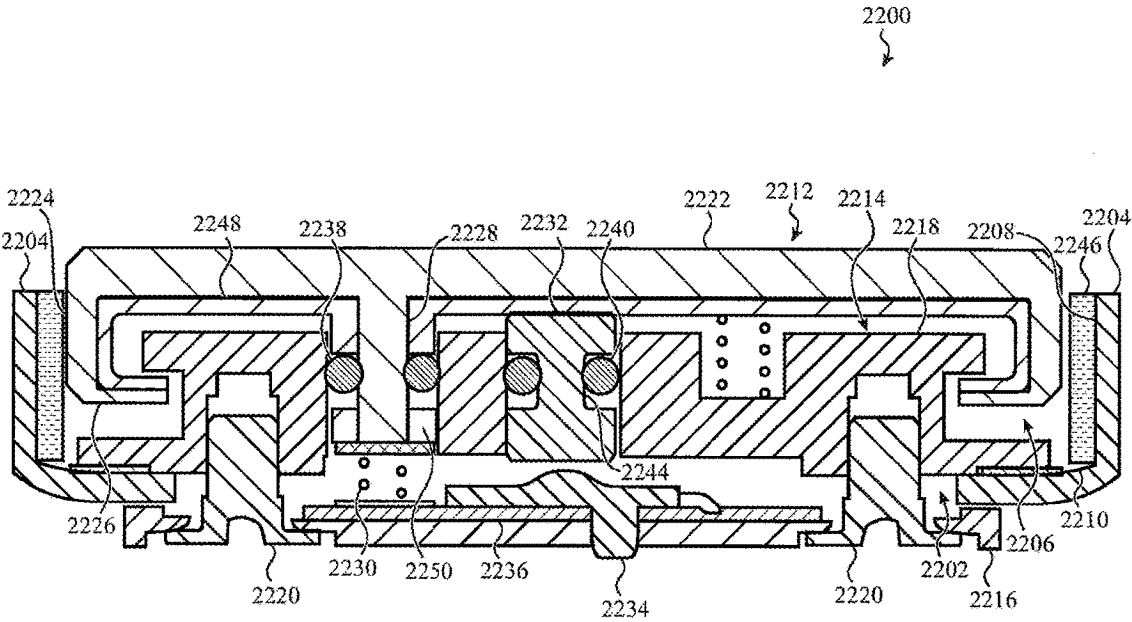


FIG. 22

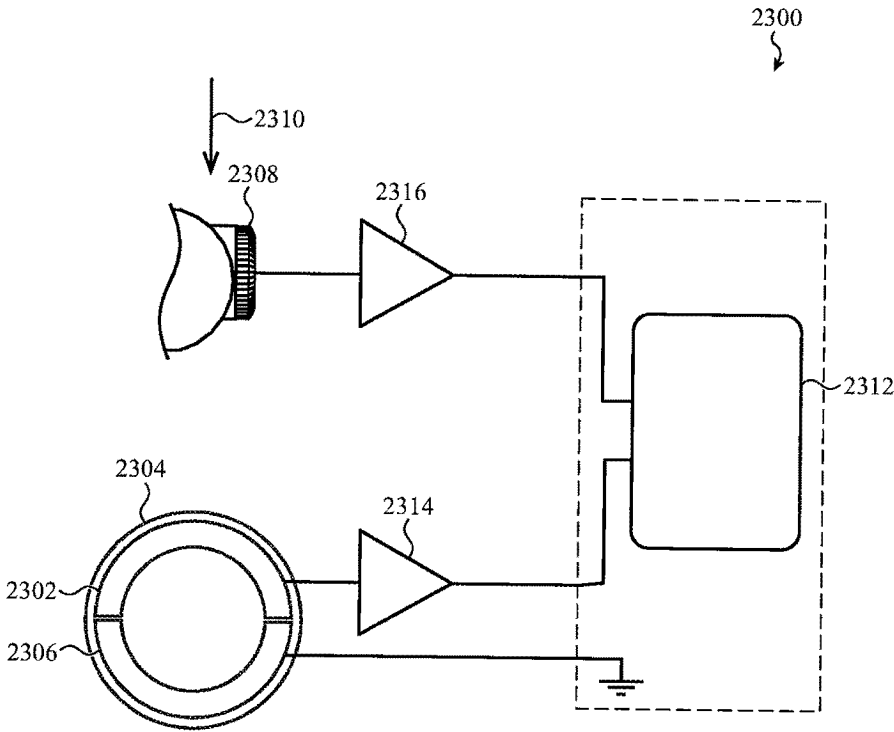


FIG. 23

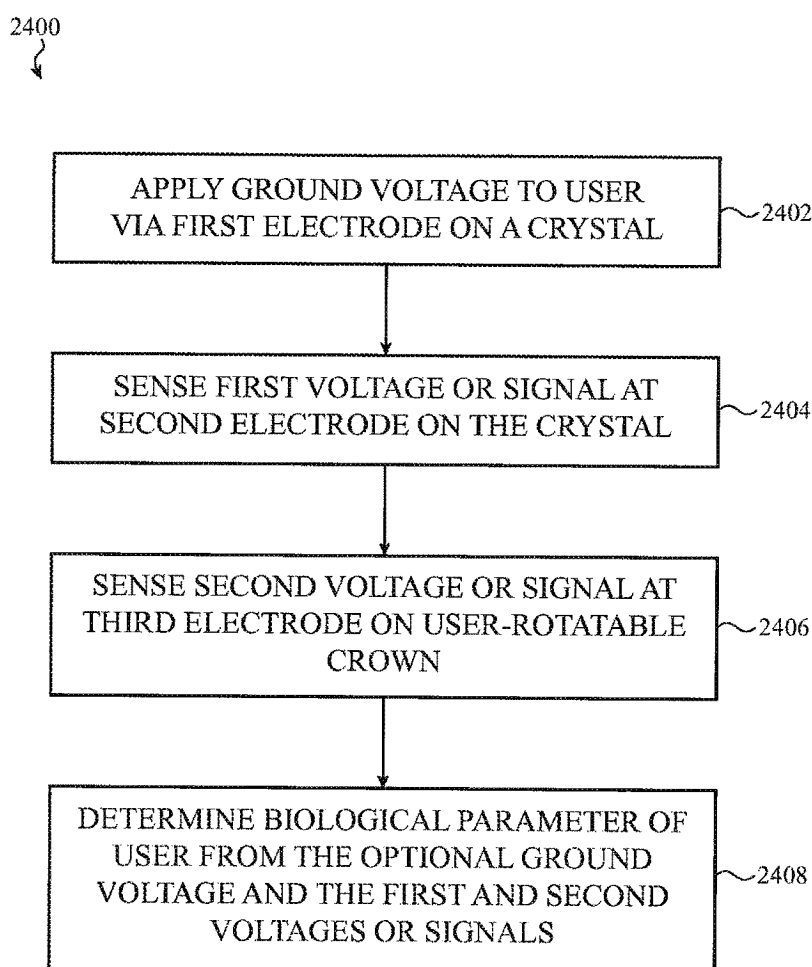


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**FIG. 24**

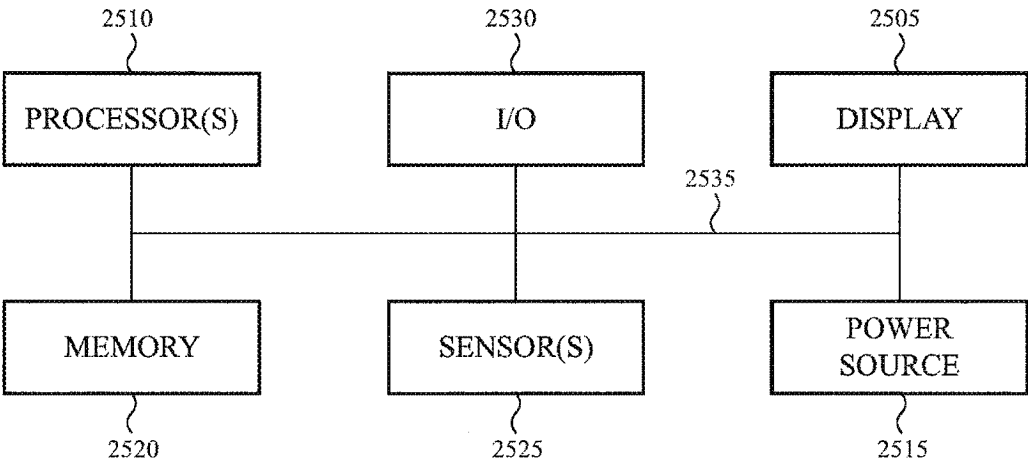


FIG. 25

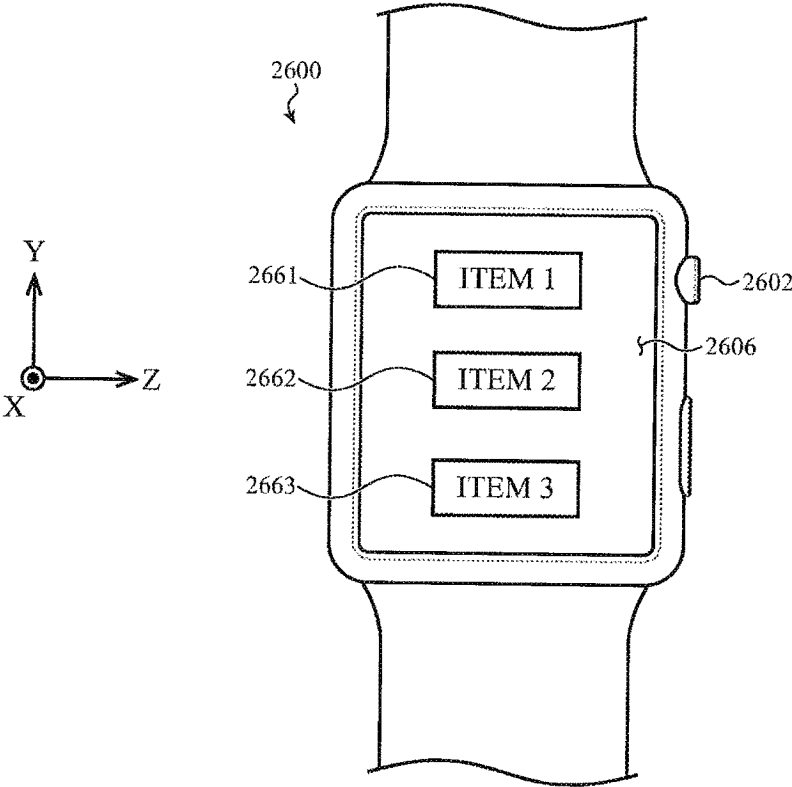


FIG. 26A

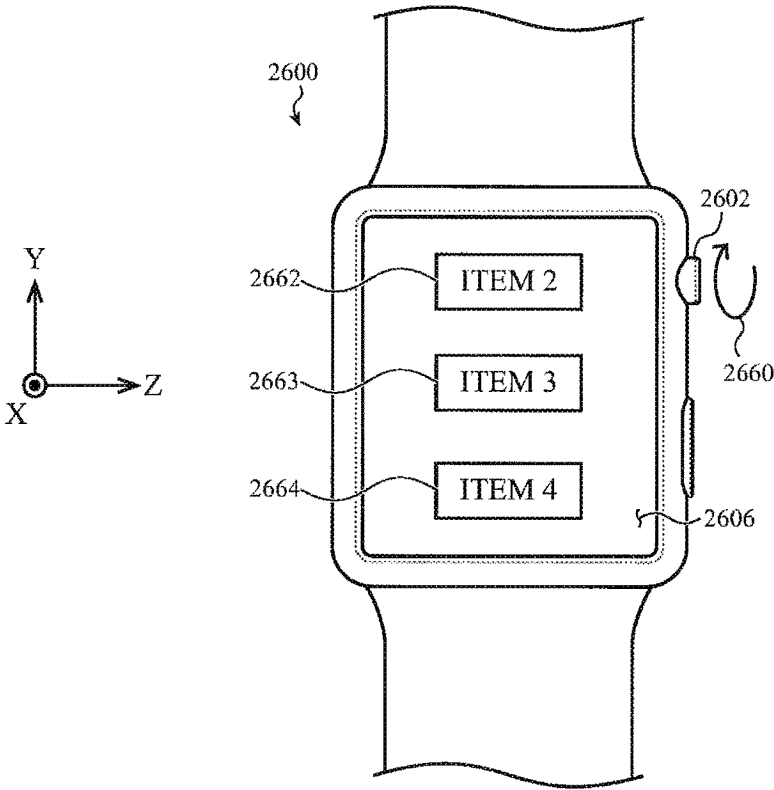


FIG. 26B

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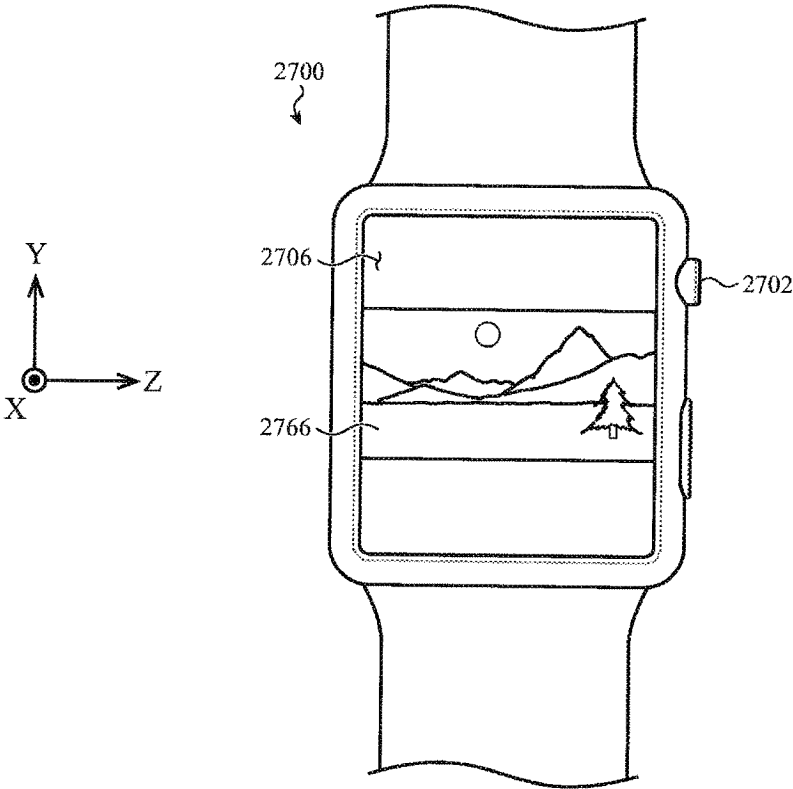


FIG. 27A

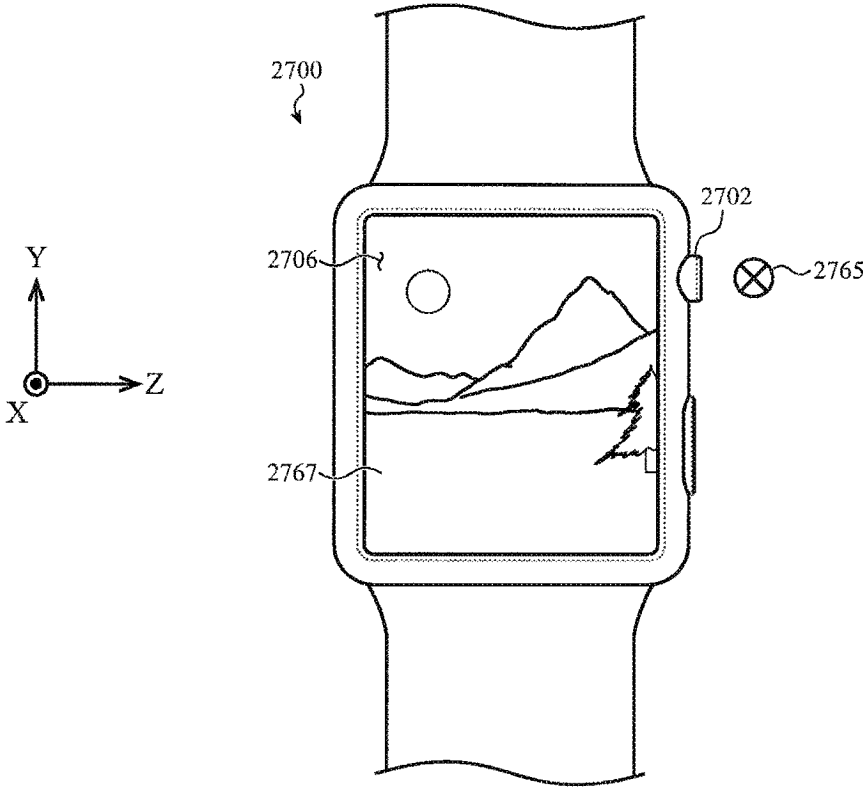


FIG. 27B



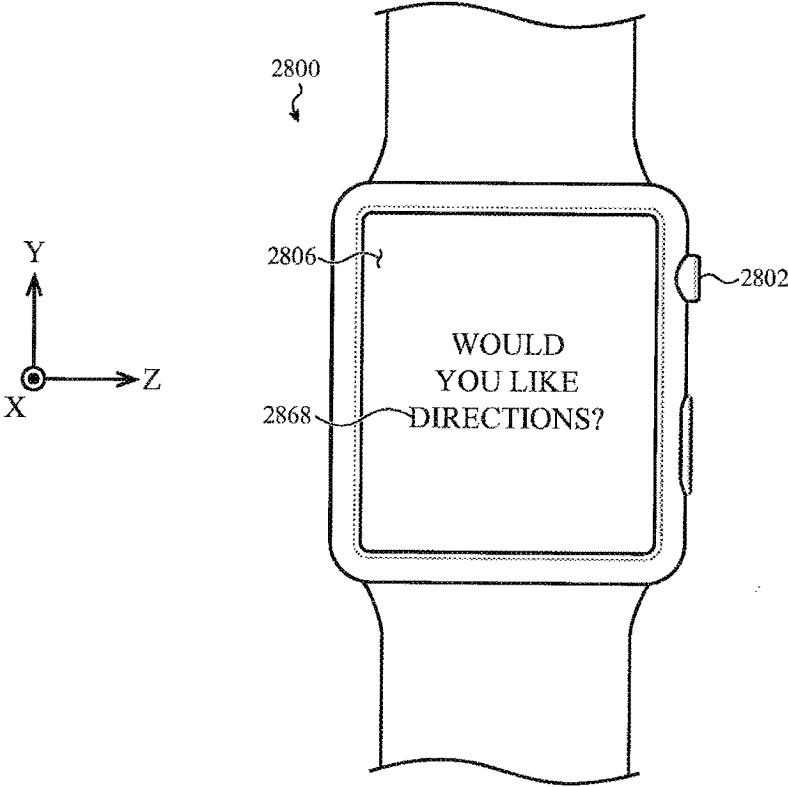


FIG. 28A

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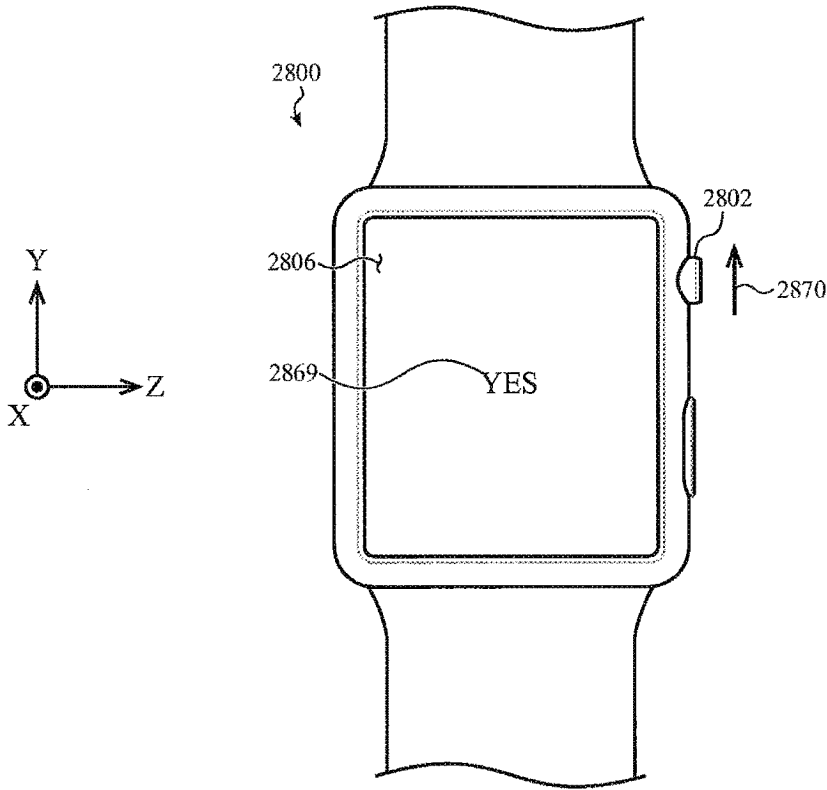


FIG. 28B

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**WEARABLE ELECTRONIC DEVICE WITH  
ELECTRODES FOR SENSING BIOLOGICAL  
PARAMETERS**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 16/193,836, filed Nov. 16, 2018, and titled “Wearable Electronic Device with Electrodes for Sensing Biological Parameters,” which is a continuation of U.S. patent application Ser. No. 16/118,282, filed Aug. 30, 2018, and titled “Wearable Electronic Device with Electrodes for Sensing Biological Parameters,” which claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 62/554,196, filed Sep. 5, 2017, and titled “Wearable Device with Electrodes for Sensing Biological Parameters,” and U.S. Provisional Patent Application No. 62/644,886, filed Mar. 19, 2018, and titled “Wearable Device with Electrodes for Sensing Biological Parameters,” the contents of which are incorporated herein by reference as if fully disclosed herein.

**FIELD**

The described embodiments relate generally to an electronic watch or other wearable electronic device. More particularly, the described embodiments relate to techniques for providing, on a watch or other wearable electronic device, electrodes for sensing biological parameters. The electrodes may be variously provided on a surface of an optical component, crown, button, or housing member of the watch or other wearable electronic device.

**BACKGROUND**

A wearable electronic device may include a set of sensors for determining a set of biological parameters of a user that wears the wearable electronic device. Circuitry associated with the set of sensors may generate, for example, electrical signals or measurements corresponding to voltages at, forces applied to, or amounts of light incident on, the sensors. The various signals or measurements may be correlated to, or used to derive, various biological parameters of the user, such as a heart rate of the user.

**SUMMARY**

Embodiments of the systems, devices, methods, and apparatuses described in the present disclosure are directed to an electronic watch or other wearable electronic device having a set of electrodes that may be used to sense or determine biological parameters of a user that wears the wearable electronic device. The biological parameters may include, for example, an electrocardiogram (ECG) of the user.

One embodiment takes the form of an electronic watch, comprising: a housing; a crown comprising: a crown body; and a shaft connected to the crown body and passing through the housing; a carrier connected to the housing; a transparent cover connected to the housing; a touch-sensitive display at least partially within the housing and viewable through the transparent cover; a first electrode on the carrier; a second electrode on the crown body; and a processor within the housing and operationally connected to the first electrode and the second electrode; wherein: the first electrode is configured to measure a first voltage; the second electrode is configured to measure a second voltage; the processor is

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configured to determine an electrocardiogram using the first voltage and the second voltage; and the touch-sensitive display is configured to display the electrocardiogram.

Another embodiment takes the form of an electronic watch, comprising: a housing; a carrier attached to the housing; a first electrode on the carrier; a crown extending through the housing and configured to translate and rotate, comprising a second electrode; and a processor operable to determine a biological parameter of a user based on voltages measured at the first electrode and the second electrode; wherein: the voltages are measured while the user is in contact with the first electrode and the second electrode.

Yet another embodiment takes the form of a method for determining and displaying an electrocardiogram by an electronic watch, comprising: measuring a first voltage at a first electrode on a crown of the electronic watch; measuring a second voltage at a second electrode on a carrier of the electronic watch; determining, by a processor of the electronic watch, the electrocardiogram using the first voltage and the second voltage; and displaying the electrocardiogram on a display of the electronic watch.

In addition to the example aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following description.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

- FIG. 1A shows a functional block diagram of a wearable electronic device;
- FIG. 1B shows an example of an electronic device having a set of electrodes disposed thereon;
- FIGS. 2A-2C show an example of an electronic watch that incorporates a set of electrodes;
- FIG. 3 shows another example of an electronic watch that incorporates a set of electrodes;
- FIGS. 4A-4D show an additional example of an electronic watch that incorporates a set of electrodes on a carrier;
- FIGS. 5A-5E illustrate an example of coatings that may be deposited on the interior and exterior surfaces of the carrier shown in FIGS. 4A-4C;
- FIG. 6 shows a cross-section of the carrier shown in FIG. 5B;
- FIG. 7 shows a cross-section of the carrier shown in FIGS. 5C and 5D;
- FIG. 8 shows an example layer construction of an ITO-based electrode;
- FIGS. 9A-9C show alternative electrical connections between an electrode on an exterior surface of a carrier that forms part of a housing of an electronic device and an electrical contact interior to the electronic device;
- FIGS. 10A-10D show alternative carrier configurations, and alternative attachments or connections of carriers to other housing members of an electronic device;
- FIG. 11A is a cross-section of an example crown assembly;
- FIG. 11B is a cross-section of another example crown assembly;
- FIGS. 12A & 12B show another example of a crown assembly;
- FIGS. 13 & 14 show cross-sections of additional examples of crown assemblies;
- FIGS. 15-22 show various examples of button assemblies;

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FIG. 23 shows a schematic of an electronic device that may be used for acquiring an ECG or other biological parameter from a user of the electronic device;  
FIG. 24 shows an example method of determining a biological parameter of a user wearing a watch or other wearable electronic device;

FIG. 25 shows a sample electrical block diagram of an electronic device such as a watch or other wearable electronic device;

FIG. 26A illustrates a sample electronic watch displaying a list;

FIG. 26B illustrates the sample electronic watch of FIG. 26A, with an updated list in response to a crown input;

FIG. 27A illustrates a sample electronic watch displaying a graphic;

FIG. 27B illustrates the sample electronic watch of FIG. 27A with the graphic updated in response to a crown input;

FIG. 28A illustrates a sample electronic watch displaying a first graphic; and

FIG. 28B illustrates the sample electronic watch of FIG. 28A displaying a second graphic in response to a crown input.

The use of cross-hatching or shading in the accompanying figures is generally provided to clarify the boundaries between adjacent elements and also to facilitate legibility of the figures. Accordingly, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, element proportions, element dimensions, commonalities of similarly illustrated elements, or any other characteristic, attribute, or property for any element illustrated in the accompanying figures.

Additionally, it should be understood that the proportions and dimensions (either relative or absolute) of the various features and elements (and collections and groupings thereof) and the boundaries, separations, and positional relationships presented therebetween, are provided in the accompanying figures merely to facilitate an understanding of the various embodiments described herein and, accordingly, may not necessarily be presented or illustrated to scale, and are not intended to indicate any preference or requirement for an illustrated embodiment to the exclusion of embodiments described with reference thereto.

DETAILED DESCRIPTION

Reference will now be made in detail to representative embodiments illustrated in the accompanying drawings. It should be understood that the following description is not intended to limit the embodiments to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as can be included within the spirit and scope of the described embodiments as defined by the appended claims.

The following disclosure relates to techniques for distributing a set of electrodes over a set of surfaces of a wearable electronic device, such as an electronic watch, and to techniques for electrically isolating the electrodes from other components of the device and/or mitigating effects of environmental factors when sensing voltages or signals indicative of one or more biological parameters of a user who is in contact with the electrodes, and to techniques for routing the voltages or signals within the device.

Embodiments further may take the form of an electronic watch, or other portable and/or wearable device, configured to detect an electrocardiogram ("ECG") of a person wearing or otherwise interacting with the electronic device. As one

non-limiting example, a person may wear an electronic watch that has two external electrodes configured to be touched by the user. A first electrode may be placed on a rear surface of the watch and be in contact with skin on the wrist of the person. A second electrode may be defined by or on a crown of the watch and may be configured to be touched by a finger (or other body part) of the person.

FIG. 1A shows a functional block diagram of a wearable electronic device 100. In some examples, the device 100 may be an electronic watch or electronic health monitoring device. The wearable electronic device 100 may include one or more input devices 102, one or more output devices 104, and a processor 106. Broadly, the input devices 102 may detect various types of input, and the output devices 104 may provide various types of output. The processor 106 may receive input signals from the input devices 102, in response to inputs detected by the input devices. The processor 106 may interpret input signals received from one or more of the input devices 102 and transmit output signals to one or more of the output devices 104. The output signals may cause the output devices 104 to provide one or more outputs. Detected input at one or more of the input devices 102 may be used to control one or more functions of the device 100. In some cases, one or more of the output devices 104 may be configured to provide outputs that are dependent on, or manipulated in response to, the input detected by one or more of the input devices 102. The outputs provided by one or more of the output devices 104 may also be responsive to, or initiated by, a program or application executed by the processor 106 and/or an associated companion device.

In various embodiments, the input devices 102 may include any suitable components for detecting inputs. Examples of input devices 102 include audio sensors (e.g., microphones), optical or visual sensors (e.g., cameras, visible light sensors, or invisible light sensors), proximity sensors, touch sensors, force sensors, mechanical devices (e.g., crowns, switches, buttons, or keys), vibration sensors, orientation sensors, motion sensors (e.g., accelerometers or velocity sensors), location sensors (e.g., global positioning system (GPS) devices), thermal sensors, communication devices (e.g., wired or wireless communication devices), resistive sensors, magnetic sensors, electroactive polymers (EAPs), strain gauges, electrodes, and so on, or some combination thereof. Each input device 102 may be configured to detect one or more particular types of input and provide a signal (e.g., an input signal) corresponding to the detected input. The signal may be provided, for example, to the processor 106.

The output devices 104 may include any suitable components for providing outputs. Examples of output devices 104 include audio output devices (e.g., speakers), visual output devices (e.g., lights or displays), tactile output devices (e.g., haptic output devices), communication devices (e.g., wired or wireless communication devices), and so on, or some combination thereof. Each output device 104 may be configured to receive one or more signals (e.g., an output signal provided by the processor 106) and provide an output corresponding to the signal.

The processor 106 may be operably coupled to the input devices 102 and the output devices 104. The processor 106 may be adapted to exchange signals with the input devices 102 and the output devices 104. For example, the processor 106 may receive an input signal from an input device 102 that corresponds to an input detected by the input device 102. The processor 106 may interpret the received input signal to determine whether to provide and/or change one or more outputs in response to the input signal. The processor



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106 may then send an output signal to one or more of the output devices 104, to provide and/or change outputs as appropriate. Examples of suitable processors are discussed in more detail below with respect to FIG. 25.

In some examples, the input devices 102 may include a set of electrodes. The electrodes may be disposed on one or more exterior surfaces of the device 100. The processor 106 may monitor for voltages or signals received on at least one of the electrodes. In some embodiments, one of the electrodes may be permanently or switchably coupled to a device ground. The electrodes may be used to provide an ECG function for the device 100. For example, a 2-lead ECG function may be provided when a user of the device 100 contacts first and second electrodes that receive signals from the user. As another example, a 3-lead ECG function may be provided when a user of the device 100 contacts first and second electrodes that receive signals from the user, and a third electrode that grounds the user to the device 100. In both the 2-lead and 3-lead ECG embodiments, the user may press the first electrode against a first part of their body and press the second electrode against a second part of their body. The third electrode may be pressed against the first or second body part, depending on where it is located on the device 100.

FIG. 1B shows an example of an electronic device 110 (here, an electronic watch) having a set of electrodes 112, 114 disposed thereon. The device 110 may be an example of the wearable electronic device described with reference to FIG. 1A, or may be an example of an electronic device that is not wearable. In some embodiments, the set of electrodes 112, 114 may be provided on one surface of the device 110. In other embodiments (as shown), the set of electrodes 112, 114 may include electrodes provided on different surfaces of the device 100, such as a first electrode 112 provided on a first surface 116 of the device 110, and a second electrode 114 provided on a second surface 118 of the device 110. Providing electrodes on different surfaces of a device may make it easier for a user to place different body parts in contact with different electrodes. For example, a user may place one or more of the electrodes (e.g., the first electrode 112) in contact with their wrist, and may touch another one or more of the electrodes (e.g., the second electrode 114) with a finger of their opposite hand. Alternatively, the user may press the electrodes 112, 114 against different parts of their body. A processor 120 of the device 110, or a processor remote from the device 110, may determine, from the voltages or signals (e.g., from stored digital samples or values representing the voltages or signals), the biological parameter(s) of the user. The biological parameter(s) may include, for example, an electrocardiogram (ECG) of the user, an indication of whether the user is experiencing atrial fibrillation, an indication of whether the user is experiencing premature atrial contraction or premature ventricular contraction, an indication of whether the user is experiencing a sinus arrhythmia, and so on.

In some embodiments, one or two thin film electrodes may be PVD deposited on an exterior surface of a structure that forms part of a housing of an electronic device. The surface may be any transparent, semi-transparent, translucent, or opaque surface made out of an amorphous solid, glass, a crystal or crystalline material (such as sapphire or zirconia), plastic, or the like. In the case of a watch (i.e., a type of electronic device), an additional electrode may be positioned on a user-rotatable crown of a watch body, on a button of the watch body, or on another surface of a housing that defines the watch body.

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When an electrode is formed on a carrier that forms part of a housing of an electronic device, the electrode may be connected to an electrical contact within the electronic device by depositing the electrode material such that it wraps around an edge or perimeter of the carrier, and onto an interior surface of the carrier. The electrical contact may be on the interior surface of the carrier. In other embodiments, the electrode may be formed on the exterior surface of the carrier, and a thru-carrier via that is filled or coated with a conductive material may connect the electrode to an electrical contact within the electronic device. The carrier may be any appropriate structure that supports the electrodes, on which the electrodes are formed, or to which the electrodes are attached. In certain embodiments described herein, the carrier is an optically transparent material having a dome shape. It should be appreciated that the carrier may have different shapes (flat, stepped, parallelepiped, and so on) and may be made from different materials, including opaque materials.

Generally, the term "attached" means that two elements, objects, structures, or objects are separate but affixed or retained to one another, whether removably, as with an electronic device attached to a user by a band, or fixedly, as with two elements that are affixed to one another with a mechanical fastener not meant to be decoupled (a screw, bolt, or the like), by an adhesive, by plating or depositing one material on another (as with an electrode deposited on the carrier), and so on. The term "connected" means that two elements may be attached to one another, or may be two parts of a unitary whole (as with a shaft and crown body formed from the same material as a single piece). Thus, while two elements that are attached to one another are necessarily connected to one another, the reverse is not necessarily true. For example, two elements may be formed as a single piece or part and thus connected to one another, although they are not attached to one another.

When an electrode is provided on a crown of an electronic device, the crown may be conductive or have a conductive surface, and the conductive portion of the crown may be coupled to a conductive rotatable shaft that extends through an opening in a device housing. An end of the shaft interior to the housing, or a conductive shaft retainer interior to the housing, may be in mechanical and electrical contact with a spring-biased conductor that carries electrical signals between the shaft or shaft retainer and a circuit, thereby providing electrical communication between the crown and the circuit.

A processor of an electronic device (e.g., the processor 120) may be operable to determine a biological parameter of a user based on voltages at various electrodes (e.g., at the set of electrodes 112, 114). In some cases, the biological parameter may be an ECG of a user of the electronic device. For example, when a watch has a first electrode on an exterior surface of a carrier and a second electrode on a crown, the user's fastening of the watch to their wrist may place the first electrode in contact with skin on the user's wrist. To acquire an ECG, the user may touch a conductive portion of the crown with a finger on their opposite hand. For example, the carrier or housing of the watch may touch a wrist adjacent one hand, and the crown may be touched with a finger of the opposite hand. In some cases, the watch may have a third electrode, also on the exterior surface of the carrier, which grounds the user to the watch. The third electrode may be used to reject noise from ECG signals. The electrodes may be positioned on different surfaces, or different portions of surfaces, in various embodiments.

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The electrode(s) on the exterior surface of the carrier may be positioned at the periphery of the carrier, or otherwise positioned to enable an optical sensor subsystem to emit and receive light through the carrier. The light may be emitted into, and reflected from, a user's skin to determine other biological parameters of the user, such as a heart rate, blood pressure, pulse, blood oxygenation, glucose level, and so on.

These and other embodiments are discussed with reference to FIGS. 1-25. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes only and should not be construed as limiting.

FIGS. 2A-2C show an example of an electronic watch 200 that incorporates a set of electrodes. The watch 200 may be an example of the wearable electronic device 100 or 110 described with reference to FIG. 1A or 1B. The watch 200 may include a watch body 202 and a watch band 204. The watch body 202 may include an input or selection device, such as a crown 210 or a button 212. FIG. 2A shows an isometric view of the watch body's front face. FIG. 2B shows an example cross-section of the crown 210. FIG. 2C shows an isometric view of the watch body's rear face. In FIGS. 2A & 2C, only a portion of the watch band 204 is shown (i.e., only the portions of the watch band 204 that attach to the watch body 202).

The watch body 202 may include a housing 206. The housing 206 may include a front side housing member 206a that faces away from a user's skin when the watch 200 is worn by a user (see FIG. 2A), and a back side housing member 206b (or rear cover) that faces toward the user's skin (see FIG. 2C). Alternatively, the housing 206 may include a singular housing member, or more than two housing members. The one or more housing members may be metallic, plastic, ceramic, crystal, or other types of housing members (or may include combinations of such materials).

As shown in FIG. 2A, a transparent cover 208 may be attached to a front side of the watch body 202 (i.e., facing away from a user's skin), over or within an opening in the housing 206, and may protect a display positioned at least partially within the housing 206. The display may be viewable by a user through the cover 208. In some embodiments, the display may depict an ECG waveform of a person who is wearing or otherwise using the watch 200. In some cases, the cover 208 may be part of a display stack, which display stack may include a touch sensing or force sensing capability. The display may be configured to depict a graphical output of the watch 200, and a user may interact with the graphical output (e.g., using a finger or stylus that touches or hovers over the cover 208, or using the crown 210 or button 212). As one example, the user may select (or otherwise interact with) a graphic, icon, indicator, message, or the like (collectively, "graphic") presented on the display by touching or pressing on the display at the location of the graphic. In some embodiments, the user may receive confirmation of their selection by means of haptic output provided by the watch body 202 through the display or cover 208. The exterior surface of the cover 208 may therefore function as a means for receiving input (i.e., function as an input device) and a means for providing output (i.e., function as an output device). The cover 208 may be attached to the housing 206 or part of the housing 206 (e.g., connected to the housing). In some embodiments, the cover 208 may be considered part of the housing 206 because it forms part of an outer shell that defines an interior volume (or houses internal components) of the watch body 202. In some examples, the cover 208

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may be or include a crystal, such as a sapphire crystal. Alternatively, the cover 208 may be formed of glass, plastic, or other materials.

The watch body 202 may include at least one input device or selection device, such as a crown 210, scroll wheel, knob, dial, button 212, or the like, which input device may be operated by a user of the watch 200. In some embodiments, the crown 210, scroll wheel, knob, dial, button 212, or the like may be conductive, or have a conductive surface, and a signal route may be provided between the conductive portion of the crown 210, scroll wheel, knob, dial, button 212, or the like and a circuit (including a processor) within the watch body 202.

The operation of determining and/or displaying a user's ECG may be initiated by rotating the crown 210, translating the crown, tilting the crown, touching the crown, and so on. Likewise the operation of determining the ECG may be initiated by interacting with a touch-sensitive cover 208 or display of the electronic watch. As discussed above, the display may be partially or fully within the housing of the electronic watch.

Turning primarily to FIG. 2B, it is shown that the housing 206 may include an opening through which a shaft 224 extends. A crown 210 may be connected to the shaft 224, and may be accessible to a user exterior to the housing 206. The crown 210 may be manipulated by a user to rotate or translate the shaft, as indicated by arrows 218 and 220. Such manipulations are examples of crown inputs. The shaft may be mechanically, electrically, magnetically, and/or optically coupled to components within the housing 206. In some embodiments, the crown 210 may be part of a crown assembly, as described with reference to FIG. 11, 12A, 12B, 13, or 14.

A user's manipulation of the crown 210 (and thus the shaft 224) may be used to manipulate or select various textual or graphical elements displayed by the watch 200, to adjust a volume of a speaker, to turn the watch 200 on or off, and so on. In some embodiments, the crown 210 may be manipulated (e.g., rotated or pressed) to select or activate a health monitoring function of the watch 200 (e.g., an ECG or other heart monitoring function). For example, a user may rotate the crown to select an ECG application, and may press the crown to activate the ECG application (e.g., initiate determination and display of a wearer's ECG). Alternatively, a user's touch or press of the crown (or touch or press of the crown for a predetermined period of time) may activate the ECG application and cause a heart rhythm of the user to be displayed. As yet another example, the user may interact with the touch-sensitive display to select and/or activate the ECG application. By way of example, a user's activation of an ECG application is indicated by the watch's display of the ECG 222 in FIG. 2A. Alternatively, the user's selection of an ECG application may be indicated by another graphic or text displayed by the watch 200. Generally, the watch 200 (and specifically its display) may change from displaying some graphic or text to displaying the ECG 222 once the ECG (or its corresponding application, or function) is initiated, selected, or determined.

As shown in FIG. 2B, the crown 210 may be connected to the shaft 224 (and may be unitary with the shaft), and the shaft 224 may extend through an opening in the housing 206. In some embodiments, the shaft 224 may be separated from the housing 206 by a bushing or other component, or retained to the housing 206 by a retention mechanism. The shaft 224 may rotate or translate with respect to the housing 206, as indicated by arrows 218 and 220, thereby providing one or more crown inputs to a processor of the electronic



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device 200. A first sensor 226 within the housing 206 may sense aspects of shaft movement such as direction of rotation, speed of rotation, rotational acceleration, or angular position of the shaft 224. In some embodiments, the first sensor 226 may be an optical sensor positioned adjacent the shaft 224, such that light 227 is emitted onto, and reflected from, the shaft 224. Light 227 may be reflected from the shaft by a pattern of surface features (such as scallops, grooves, indentation, projections, or the like) or by byproducts of machining the shaft, such as bumps, scratches, irregularities, and so on. The pattern and speed of light 227 reflected onto the optical sensor 226 may be used to determine a direction and/or speed of rotation of the shaft 224. In other embodiments, different sensors may be used to detect direction and/or speed of rotation of the shaft 224, including mechanical sensors, electrical sensors, capacitive sensors, brush contacts, magnetic sensors, and so on.

A second sensor 228 within the housing 206 may sense aspects of shaft movement such as translation or direction of translation. In some embodiments, the second sensor 228 may be a tactile switch, optical sensor, magnetic sensor, capacitive sensor or the like positioned at an end of the shaft 224.

A third sensor 230 within the housing 206 may sense when a user is touching the crown 210, or may sense signals (e.g., a heart rhythm) received by the crown 210 when a user touches the crown 210. In some embodiments, the third sensor 230 may be electrically coupled to the crown 210 or shaft 224. In some cases, the sensors 226, 228, 230 may be provide signals or information to the processor 214, or may be partly or wholly integrated with the processor 214 or other components of the watch 200. In some embodiments, two or more of the sensors 226, 228, 230 may be combined into a multipurpose sensor. In some embodiments, one or more of the sensors 226, 228, 230 may not be provided. In some embodiments, the functions of one of the sensors 226, 228, 230 may be distributed among multiple sensors, or additional crown sensors may be provided.

Any or all of the first sensor 226, second sensor 228, and third sensor 230 may be attached to or otherwise supported by one or more internal supports 232, as shown in FIG. 2B.

Turning primarily to FIG. 2C, the housing 206 may include structures for attaching the watch band 204 to the watch body 202. In some cases, the structures may include elongate recesses or openings through which ends of the watch band 204 may be inserted and attached to the watch body 202. In other cases (not shown), the structures may include indents (e.g., dimples or depressions) in the housing 206, which indents may receive ends of spring pins that are attached to or threaded through ends of a watch band to attach the watch band to the watch body 202.

The watch band 204 may be used to secure the watch 200 to a user, another device, a retaining mechanism, and so on.

As previously mentioned, the watch 200 may include a set of electrodes. The set of electrodes may be configured, in some cases, as described with reference to FIG. 1A or 1B. The set of electrodes may be used by a processor 214 that is internal to the watch body 202, to sense biological parameters (e.g., an ECG) of a person who wears the watch 200 and presses the electrodes against their skin. In some embodiments, the set of electrodes may include a rear-facing electrode 216 on the back of the watch body 202 (e.g., on the back side housing member 206b). The set of electrodes may also include an electrode on the crown 210 and/or an electrode on the button 212.

The rear-facing electrode 216 may be formed (e.g., printed, plated, or otherwise deposited) on the back side

housing member 206b. If the back side housing member 206b is non-conductive, the rear-facing electrode 216 may be formed directly on the back side housing member 206b and connected to circuitry internal to the watch body 202 (e.g., the processor 214) by, for example, conductive vias formed through the back side housing member 206b. If the back side housing member 206b is conductive, the rear-facing electrode 216 may be separated from the back side housing member 206b by an insulator or insulating layer, and conductive vias formed through the back side housing member 206b may likewise be insulated from the back side housing member 206b. Alternatively, the back side housing member 206b may have an opening to which the rear-facing electrode 216 is mated. In some embodiments, the opening may define a ledge in the back side housing member 206b, and the rear-facing electrode 216 may rest on the ledge (and in some cases may be separated from the back side housing member 206b by an insulator (e.g., a seal) or an insulating layer).

The electrode(s) on the crown 210 or button 212 may be conductive surfaces of the crown 210 or button 212. In some cases, the crown 210 or button 212 may be conductive over its entire exterior surface. In other cases, the crown 210 or button 212 may have conductive portions (e.g., cores or inserts). When the front side housing member 206a is conductive, the crown 210 or button 212 (or the conductive components thereof) may be insulated from the front side housing member 206a by an insulator (e.g., a set of seals, non-conductive coatings, and so on).

In some embodiments, one of the crown 210 or button 212 may have an electrode thereon, and a user wearing the watch 200 on one of their wrists may touch the electrode on the crown 210 or button 212 with a finger of their opposite hand. The processor 214 may then use the electrodes to acquire an ECG for the user. In other embodiments, both the crown 210 and the button 212 may have an electrode thereon, and a user wearing the watch 200 on one of their wrists may touch the electrodes on the crown 210 and button 212 with a finger of their opposite hand. In still other embodiments, the entirety of the back side housing member 206b (or even the entirety of the housing 206) may be an electrode. In these latter embodiments, electrical isolation may be provided between the housing 206 and the crown 210 and/or between the housing 206 and the button 212.

In some examples, the watch 200 may lack the display, the crown 210, or the button 212. For example, the watch 200 may include an audio input or output interface, a touch input interface, a haptic (force) input or output interface, or other input or output interface that does not require the display, crown 210, or button 212. The watch 200 may also include the afore-mentioned input or output interfaces in addition to the display, crown 210, or button 212. When the watch 200 lacks the display, the front face of the watch 200 may be covered by the cover 208, or by a metallic or other type of housing member (e.g., the opening for the cover 208 may not exist, and the front side housing member 206a may extend over the area defined by the cover 208). In these embodiments, the electrode(s) on the crown 210 or button 212 may be replaced by (or supplemented with) an electrode on the front face of the watch body 202. A user may touch the front-facing electrode with a finger, similarly to how they would touch an electrode on the crown 210 and/or button 212. Alternatively, a user could place the front-facing electrode in contact with, for example, an opposite wrist, part of their leg, or their torso or forehead.

In some embodiments, the watch 200 may lack the rear-facing electrode 216, and each of the crown 210 and the

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button 212 may have a conductive surface that serves as an electrode. In these embodiments, the watch 200 may need to be removed from a user's wrist to enable the user to press different parts of their body against the crown and button electrodes. In some embodiments, the crown 210 or the button 212 may be moved to an opposite side of the watch body 202, thereby increasing the separation between the crown 210 and the button 212 and making it easier for a user to press different parts of their body against the crown and button electrodes.

Other electronic devices that may incorporate a set of electrodes include other wearable electronic devices, other timekeeping devices, other health monitoring or fitness devices, other portable computing devices, mobile phones (including smart phones), tablet computing devices, digital media players, or the like.

Because the voltages or signals provided at, propagated from, or monitored at the various electrodes of a set electrodes may be low voltage or have low amplitudes, the materials, positions, electrical connections to, and electrical routing paths for the set of electrodes can have a significant impact on a processor's ability to discern useful signals representing an ECG or other biological parameter of a person wearing the watch 200 or a similar device (e.g., one of the other watches or electronic devices described herein). The materials, positions, electrical connections to, and electrical routing paths for the set of electrodes can determine how well the electrodes receive voltages/signals from the person's skin (e.g., a signal-to-noise ratio (SNR) of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the electrodes and internal components of the watch 200 (e.g., a voltage/signal propagation SNR); and how well the electrodes operate in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. Techniques described in the present disclosure may improve the usability of a set of electrodes under some or all of these conditions.

FIG. 3 shows another example of an electronic watch 300 that incorporates a set of electrodes. The watch 300 may be an example of the wearable electronic device 100 or 110 described with reference to FIG. 1 or 1B, and may include many of the components of the watch 200 described with reference to FIGS. 2A-2C. The watch 300 may include a watch body 202 and a watch band 204. FIG. 3 shows an isometric view of the watch body's rear face. Only a portion of the watch band 204 is shown (i.e., only the portions of the watch band 204 that attach to the watch body 202).

The watch 300 in FIG. 3 differs from the watch 200 of prior figures in that it has a different set of internal components, a different back side housing member 302, and a different set of elements that are provided or exposed on the back side housing member 302. For example, the watch 300 may include a sensor subsystem that includes both electrical and optical components. The electrical components may include one or more electrodes 304, 306 formed on the back side housing member 302. In some cases, each of the electrodes 304, 306 may have a circular shape and may be PVD deposited on the back side housing member 302. Alternatively, only one, or more than two electrodes may be formed on the back side housing member 302, or the electrodes 304, 306 may be positioned over (or inset into) openings in the back side housing member 302.

The optical components of the sensor system may include a set of one or more windows 308, 310, 312, 314 in the back side housing member 302. Each of the windows 308, 310, 312, 314 may pass at least one wavelength of light. In some

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cases, each of the windows 308, 310, 312, 314 may have a semicircular shape. The windows may alternatively have other shapes. The windows may be formed of crystal, glass, plastic or another material that passes at least one wavelength of light emitted or received by the sensor subsystem.

In some embodiments, the back side housing member 302 may be or include a transparent cover (e.g., a cover including a crystal, such as a sapphire crystal, or glass, or plastic, or the like), and may be substantially flat or planar (as shown) or may be curved or otherwise non-planar. A mask (e.g., an ink mask and/or dark mask) may be applied to the transparent cover to define the windows 308, 310, 312, 314. The electrodes 304, 306 may be formed on top of the mask or over openings in the mask.

In some embodiments, the back side housing member 302 may be an opaque substrate, such as a metal or plastic substrate, and one or more transparent windows 308, 310, 312, 314 may be fitted to openings in the substrate. The transparent windows may be fitted to the openings internally to (or externally from) the watch body 202. The electrodes 304, 306 may be fitted to additional openings that enable the electrodes 304, 306 to protrude outward from the external surface of the back side housing member 302, or the electrodes 304, 306 may be formed on the surface of the back side housing member 302 and the electrically connected to components internal to the watch body 202 by conductive vias or other elements formed through the surface of the back side housing member 302.

By way of example, FIG. 3 shows the electrodes 304, 306 aligned along a first axis that divides the back side housing member 302 into two halves, and shows the windows 308, 310, 312, 314 aligned along a second axis, perpendicular to the first axis, that divides the back side housing member 302 into a different two halves. In this manner, the electrodes 304, 306 and windows 308, 310, 312, 314 may form four circular areas on the exterior surface of the back side housing member 302, with the circular areas that contain the windows 308, 310, 312, 314 appearing bifurcated.

In use, each pair of windows 308/310, 312/314 forming a circular area may include a first window under which one or more light emitters are positioned, and a second window under which one or more light receivers are positioned, with an optional set of one or more light blocking walls positioned between the one or more light emitters and the one or more light receivers (or around the light emitter(s), or around the light receiver(s)).

FIGS. 4A-4D show an additional example of an electronic watch 400 that incorporates a set of electrodes. The watch 400 may be an example of the wearable electronic device 100 or 110 described with reference to FIG. 1A or 1B, and may include many of the components of the watch 200 described with reference to FIGS. 2A-2C. The watch 400 may include a watch body 202 and a watch band 204. FIG. 4A shows an isometric view of the watch body's rear face. Only a portion of the watch band 204 is shown (i.e., only the portions of the watch band 204 that attach to the watch body 202).

Similarly to the watch 300 described with reference to FIG. 3, the watch 400 may include a sensor subsystem that includes both electrical and optical components. However, the electrical and optical components of the watch 400 may be arranged differently than the electrical and optical components of the watch 300.

Referring primarily to FIG. 4A, a light-transmissive element such as a carrier 404 (e.g., a rear-facing or skin-facing carrier) may be coupled to or otherwise attached to a back side housing member 402 of the watch 400, and in some



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cases may be considered to form a part of the housing 206 of the watch body 202. The carrier 404 may have a first surface 406 that is inferior to the watch body 202 (see FIG. 4C) and a second surface 408 that is exterior to the watch body 202 (see FIG. 4A). The carrier 404 may be dome-shaped or otherwise non-planar, as shown in FIGS. 4A-4C, such that the second surface 408 protrudes or extends away from a back member 402 of the watch 400. This is best illustrated in FIGS. 4B and 4C.

By way of example, the carrier 404 is shown as having a round perimeter and fitted to a round opening in the back side housing member 402. In other examples, the carrier 404 may have a perimeter that is square, oval, or some other shape. Similarly, the opening in the back side housing member 402 may be square, oval, or some other shape. The perimeter of the carrier 404 and the perimeter of the opening need not have the same size or shape (e.g., the perimeter of the opening in the back side housing member 402 may be smaller or differently shaped than the perimeter of the carrier 404). In some examples, the carrier 404 may be a sapphire crystal. Alternatively, the carrier 404 may be formed from (or replaced by) a light-transmissive element formed of glass, plastic, or another material. The carrier 404 may be transparent to all wavelengths of light or just some wavelengths (and even one wavelength) of light.

The exterior surface 408 of the carrier 404 may have a set of electrodes (e.g., first and second (or rear-facing) electrodes 412, 414) thereon, although in some embodiments a single electrode or more than two electrodes may be used. In some embodiments, the electrodes 412, 414 may be PVD deposited on the carrier 404. Example constructions of the electrodes 412, 414 and masks 422 are described with reference to FIGS. 5A-5E, 6-8, 9A-9C, & 10A-10D. In some embodiments, the electrodes 412, 414 may be opaque. In other examples, the electrodes 412, 414 may be formed of a transparent material, as described with reference to FIG. 6, and the optical sensor subsystem 416 may transmit/receive light through the electrodes 412, 414. The optical sensor subsystem 416 may be, for example, an optical heart rate sensor.

In some cases, the first and second electrodes 412, 414 may be arc-shaped (e.g., semi-circle-shaped), and may be positioned around a central opening 418 and concentric ring of openings 420 formed in the masks 422. The first and second electrodes 412, 414 may extend to the edge of the carrier 404, and in some cases may wrap around the perimeter of the carrier 404 to the interior surface 406 of the carrier 404, or be connected to conductive vias formed in the carrier 404, or otherwise be electrically connected to elements within the watch body 202 that receive a signal sensed by one or both of the first and second electrodes 412, 414. In some cases, the first and second electrodes 412, 414 may be electrically insulated from the back side housing member 402 (e.g., by a non-conductive gasket or adhesive), or the back side housing member 402 may be non-conductive. In some cases, the first and second electrodes 412, 414 may be formed of, or include, stainless steel (SUS) or diamond like carbon (DLC).

The electrodes 412, 414 may be positioned (e.g., at the periphery of the carrier 404 or in other locations) so as not to interfere with optical communication between an optical sensor subsystem 416 interior to the watch body 202 (see FIG. 4C) and a medium (e.g., skin) exterior to the watch body 202. The optical communication may occur through the carrier 404, and in some cases may occur through a number of openings 418, 420 formed in one or more masks

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422 applied to the carrier 404. The optical sensing subsystem is discussed in more detail, below.

FIG. 4B shows an elevation of the watch body 202 shown in FIG. 4A. The exterior of the watch body 202 is defined primarily by the housing 206, the transparent cover 208, and the carrier 404. The carrier 404 supports the rear-facing electrodes 412, 414 (e.g., as described with reference to FIGS. 4A, 4C, 5C, 5D, 5E, 6-8, 9A-9C, & 10A-10D). The element 430 may represent the crown 210 or button 212. For ease of explanation, it is noted that the positions of the electrodes 412, 414 on the carrier 404 have been rotated 90 degrees with respect to their positions in FIGS. 4A & 4C.

The watch body 202 may be abutted to a user's wrist 432 or other body part, and may be adhered to the user by the watch band 204 or another element. When abutted to a user's wrist 432, the electrodes 412, 414 on the carrier 404 may contact the user's skin. The user may touch a conductive portion of the element 430 with a finger 434. The user may touch the element 430 in various ways, depending on where the element 430 is conductive, and depending on the user's preference. In some cases, the user may touch the element 430 while also touching their wrist 432. However, high skin-to-skin impedance tends to reduce the likelihood that signals will travel from the electrodes 412, 414, through their wrist 432 to their finger 434, and subsequently to the element 430 (or vice versa). In some cases, the user may touch the element 430 while also touching the housing 206, which may be okay if the housing 206 is not conductive.

FIG. 4C shows an exploded view of components that may be attached to the interior surface 406 of the carrier 404 shown in FIGS. 4A & 4B. When the watch body 202 shown in FIGS. 4A & 4B is assembled, the components shown in FIG. 4C may reside within the housing 206. By way of example, FIG. 4C shows the components in relation to the back side housing member 402 (i.e., in relation to a skin-facing housing member).

In some cases, the interior components shown in FIG. 4C may be attached to (and in some cases directly on) the interior surface 406 of the carrier 404. The interior surface 406 may sometimes be referred to as a first surface of the carrier 404. The components attached to the carrier 404 may include a lens 436, a light filter 438, one or more adhesives 440, 442, the optical sensor subsystem 416, circuitry or a processing subsystem 444, a magnet 446, or a magnetic shield 448.

The lens 436 may abut, be attached to (and optionally, directly on), or be formed on the first or interior surface 406 of the carrier 404. By way of example, the lens 436 is aligned with the center of the carrier 404. In some cases, the interior or exterior surface 406, 408 of the carrier 404 may have a mask 422 thereon (e.g., an ink mask or dark mask, and in some cases a plurality of masks). The mask 422 may define an opening 418 (e.g., a first opening or central opening) that allows light of at least one wavelength to pass through the carrier 404, and the lens 436 may be aligned with the opening 418. In some cases, the lens 436 may be or include a Fresnel lens, a spherical lens, a diffuser film, or the like.

In some cases, the light filter 438 may include one or more segments 450, and each segment 450 may be attached to (e.g., laminated to) the interior surface 406 of the carrier 404 and positioned on the interior surface (e.g., adjacent or around the lens 436) to prevent a set of one or more light receivers of the optical sensor subsystem 416 from receiving a portion of the light that is emitted by a set of one or more light emitters of the optical sensor subsystem 416. The set of light emitters and set of light receivers are not shown in FIG.

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4C, and may be attached to an underside of the optical sensor subsystem 416. When the carrier 404 includes the mask 422, the mask 422 may further define a second opening 420a, or a set of openings 420 including the second opening 420a. The second opening 420a or set of openings 420 may be positioned adjacent or around the first opening 418. In these embodiments, the segments 450 of the light filter 438 (or a light filter ring or other light filter configuration) may be aligned with (e.g., may cover) each of the openings in the set of openings 420.

As an example, FIG. 4C shows a mask 422 that defines a set of eight radial openings 420 around a central opening 418. Each segment 450 of the light filter 438 may block (e.g., absorb) a portion of light emitted by a set of light emitters that is attached to the optical sensor subsystem 416, which portion of light reflects from a surface too close to (or within) the carrier 404 (e.g., the exterior surface 408 of the carrier 404, imperfections within the carrier 404, or a medium too close to the carrier 404), such that the reflected light is not useful in a sensing operation for which the optical sensor subsystem 416 is designed. For example, when the optical sensor subsystem 416 is configured to determine a biological parameter of a user, light reflected from the carrier 404, or from the outer layer of skin of the user, may not have any relation to the biological parameter determined and may not be useful. Accordingly, the filter may be configured to filter out light frequencies associated with light reflected from the carrier and/or a skin surface, allowing light reflected from deeper skin layers, blood vessels, and the like to be received by the receiver(s). In some examples, the light filter 438 or segments 450 thereof may include at least one of a light control film, a light polarizer, an anti-reflective film, a reflective film, or a light absorber. Accordingly and as one non-limiting example, the optical sensor subsystem 416 may act as an optical heart rate detector.

In some embodiments, the mask 422 may represent multiple masks, and different masks may allow different wavelengths of light to pass through the carrier 404, as described for example with reference to FIGS. 5A-5E & 6.

The optical sensor subsystem 416 may include a substrate 452 on which the set of one or more light emitters (e.g., LEDs) and the set of one or more light receivers (e.g., photodetectors, such as photodiodes) are attached. The light emitter(s) and light receiver(s) may be attached or positioned on the substrate 452 to emit and receive light through the carrier 404. The sensor subsystem 416 may be attached to the carrier 404 by one or more adhesives 440/442, such as pressure sensitive adhesives (PSAs) or heat-activated films (HAFs). In some cases, the set of light emitters may be centrally attached on the substrate 452, and a first wall may be attached to (e.g., formed on or bonded to) an underside of the substrate 452 surrounding the set of light emitters. The first wall may be attached to the interior surface 406 of the carrier 404 using a first adhesive 440. The set of light receivers may be attached on the substrate 452 around the set of light emitters, between the first wall and a second wall attached to (e.g., formed on or bonded to) the underside of the substrate 452. The second wall may be attached to the interior surface 406 of the carrier 404 using a second ring of adhesive 442.

The substrate 452 of the optical sensor subsystem 416 may include various contacts, pads, traces, or other conductive structures 454 that enable the processing subsystem 444 to be electrically coupled to the set of light emitters and set of light receivers of the optical sensor subsystem 416. The processing subsystem 444 may include a substrate 456 (e.g., a printed circuit board (PCB)) that is attached to the optical

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sensor subsystem 416, and thereby to the carrier 404, via the conductive structures 454 and/or additional adhesive between the substrates 452, 456 of the optical sensor subsystem 416 and the processing subsystem 444. The substrates 452, 456 may also or alternatively be connected using mechanical fasteners (e.g., screws). The processing subsystem 444 may activate the light emitters and light receivers to perform a sensor function (e.g., to determine a heart rate). In some cases, the processing subsystem 444 may be attached to another structure within the watch body, and may be electrically connected to the conductive structures 454 of the optical sensor subsystem 416 by a flex circuit or other conductors.

In some embodiments, the substrate 456 of the processing subsystem 444 may have a hole 458 therein, and the magnet 446 may be aligned with the hole 458 and abutted to (or attached to) the substrate 452. In some cases, the magnet 446 may be adhesively bonded to the substrate 452 of the optical sensor subsystem 416. The magnet 446 may inductively couple to a battery charger used for charging a battery included within the watch body, which battery may power components of the watch including the components of the optical sensor subsystem 416 and the processing subsystem 444.

The magnetic shield 448 may abut (or be attached to) the magnet 446. In some cases, the magnetic shield 448 may be adhesively bonded to the magnet 446. The magnetic shield 448 may direct magnetic flux associated with the magnet 446 toward and out the carrier 404 to improve inductive battery charging performance for a battery included within the watch body 202.

Direct or indirect connection of the components shown in FIG. 4C to the interior surface 406 of the carrier 404 can reduce the height of the components when stacked.

FIG. 4D shows the sensor subsystem 416 attached to the carrier 404 shown in FIGS. 4A-4C. FIG. 4B also shows a flex circuit 460, surrounding the sensor subsystem 416, which may provide electrical connections between the electrodes 412, 414 and the sensor subsystem 416 while also providing a ground that operates as an electrical noise mitigation barrier (or E-shield) between the sensor subsystem 416 and the electrodes 412, 414. The electrodes 412, 414 may be connected to the electrical contacts 462, 464, which electrical contacts 462, 464 are on the interior surface of the carrier 404 and connected to both traces in the flex circuit 460 and the electrodes 412, 414. Traces in the flex circuit 460 may be connected to the electrical contacts 462, 464 via a conductive epoxy, and may connect the electrical contacts 462, 464 to the sensor subsystem 416. A processor may be part of the sensor subsystem 416, and the processor may be connected to another processor or other circuitry via a flex circuit 466.

FIGS. 5A-5E illustrate an example of coatings that may be deposited on the interior and exterior surfaces of the carrier 404 shown in FIGS. 4A-4C. As shown in FIG. 5A, a first mask 500 (e.g., a first ink mask) that is opaque to infrared (IR) and visible light may be deposited (e.g., PVD deposited) on the interior surface 406 of the carrier 404. In some examples, the first mask 500 may include an inner ring 500a and an outer ring 500b that define a central first opening 418 and a concentric second opening 506 (i.e., a second opening 506 that is concentric with the first opening 418). The central first opening 418 may be positioned over light emitters of the optical sensor subsystem 416 described with reference to FIG. 4C (and over the optional lens 436), and the concentric second opening 506 may be positioned above light receivers of the sensor subsystem 416. The inner



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ring 500a of the first mask may prevent the light receivers from receiving light that is unlikely to have passed through a user's skin after passing through the central first opening 418. The outer ring 500b of the first mask 500 may in some cases be provided for cosmetic reasons, and in some cases may not be provided.

FIG. 5B shows a second mask 508 (e.g., a second ink mask) that is opaque to visible light but transparent to IR light. The second mask 508 may be deposited (e.g., PVD deposited) on the interior surface 406 of the carrier 404. The second mask 508 may be deposited on the carrier 404 over the concentric second opening 506 in the first mask 500, and may overlap the inner and outer rings 500a, 500b of the first mask, as shown in FIG. 6. The second mask 508 may define a plurality of visible light openings 420 above respective light receivers of the optical sensor subsystem 416, while allowing IR light to pass through the entirety of the concentric second opening 506. This may increase the amount of IR light received by the light receivers. The second mask 508 may also define an optional opening above a condensation detector 512. In some cases, the second mask 508 may look visually similar to the first mask 500 (e.g., both masks may be dark masks, such that it may be impossible or difficult for a user to visually distinguish the first and second masks 500, 508).

FIGS. 5C and 5D show an example of PVD deposited first and second electrodes 514a, 514b on the interior and exterior surfaces 406, 408 of the carrier 404. The first and second electrodes 412, 414 may be arc-shaped and positioned at the periphery of the carrier 404. The first and second electrodes 412, 414 may be sized based on factors such as: providing a sufficient area to provide good electrical contact between the electrodes 412, 414 and skin (which may improve electrical sensor efficiency); providing electrodes 412, 414 of a size that do not substantially interfere with an antenna or other electrical structures of a device (which may improve wireless communication efficiency); or providing electrodes 412, 414 positioned to allow optical communication through the carrier 404 (which may improve optical communication efficiency). The first and second electrodes 412, 414 may be separated from one another by a pair of gaps 518a, 518b.

The first and second electrodes 412, 414 may be deposited on both the interior and exterior surfaces 406, 408 of the carrier 404 and may wrap around the edge (or perimeter) of the carrier 404. The material used to form the first and second electrodes 412, 414 may be patterned to form electrical contacts 520a, 520b (e.g., tabs) on the interior surface 406 of the carrier 404. The first and second electrodes 412, 414 may overlap the first mask 500 (or outer ring 500b of the first mask) on the interior surface 406 of the carrier 404, such that the first mask 500 is positioned between the first and second electrodes 412, 414 and the interior surface 406 of the carrier 404. Thus, the material used to form the electrodes 412, 414 may need to have properties that enable the material to adhere to a carrier surface (e.g., a sapphire surface) and a mask (e.g., an ink mask). The material or materials used to form the electrodes 412, 414 may also have properties, singularly or in combination, such as: a low impedance and good conductivity (e.g., a low DC resistance); a low electrode-to-skin impedance; a high hardness to reduce scratching of the electrodes 412, 414; a higher elastic modulus than the carrier 404 (e.g., to mitigate the likelihood that a crack in an electrode 412, 414 propagates through the carrier 404); compatibility with a HAF or other adhesive; and good biocompatibility (e.g., not likely to cause an adverse reaction to a user of a device). In some embodiments, the electrodes 412, 414 may include alumi-

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num titanium nitride (AlTiN) or chromium silicon carbonitride (CrSiCN). AlTiN and CrSiCN hold up well to abrasion and corrosion and tend not to place undue stresses on a sapphire carrier.

FIG. 5E shows an example deposition of adhesive on the interior surface 406 of the carrier 404. The adhesive may be deposited in inner and outer rings 440, 442, as described with reference to FIG. 4C. The inner ring 440 of adhesive may be positioned on the inner ring 500a of the first mask. The outer ring 442 of adhesive may be positioned on the second mask 508, outward from the plurality of openings 420 in the second mask 508. In some cases, the adhesive may include a PSA or HAF.

FIG. 6 shows a cross-section of the carrier 404 shown in FIG. 5B, and illustrates an overlap between the first and second masks 500, 508. The second mask 508 may overlap the first mask (e.g., outer ring 500b) on the interior surface 406 of the carrier 404 such that the first mask 500 is positioned between the second mask 508 and the interior surface 406 of the carrier 404.

FIG. 7 shows a cross-section of the carrier 404 shown in FIG. 5C or 5D, and illustrates an overlap between the first electrode 412 (or second electrode) and the first mask 500 (e.g., outer ring 500b of the first mask). The first electrode 412 may overlap the first mask 500 (or outer ring 500b of the first mask) on the interior surface 406 of the carrier 404, such that the first mask 500 is positioned between the first electrode 412 and the interior surface 406 of the carrier 404.

In some embodiments, the electrodes 412, 414 shown in FIGS. 5C, 5D, and 7 may be formed using indium titanium oxide (ITO) or another transparent material. In these embodiments, the electrodes 412, 414 may be transparent to light emitted by a sensor subsystem positioned below the carrier 404, and thus the electrodes 412, 414 may extend over a greater portion (or all) of the exterior surface 408 of the carrier 404. FIG. 8 shows an example layer construction of an ITO-based electrode. As shown, the stack 800 may include a layer 802 of aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) on the carrier, a layer 804 of ITO on the layer 802 of aluminum oxide, a first layer 806 of silicon dioxide (SiO<sub>2</sub>) on the layer 804 of aluminum oxide, a layer 808 of silicon nitride (Si<sub>3</sub>N<sub>4</sub>) on the first layer 806 of silicon dioxide, a second layer 810 of silicon dioxide on the layer 808 of silicon nitride, and a layer 812 of diamond like carbon, or another hard coating, on the second layer 810 of silicon dioxide. Alternatively, the layer 808 of silicon nitride and second layer 810 of silicon dioxide may not be deposited, or only the layer 804 of ITO may be deposited, or just the layer 804 of ITO layer and first layer 806 of silicon dioxide may be deposited. Other variations in the number or types of layers may also be used to form the stack 800. Each of the layers may be transparent to IR or visible light.

FIGS. 9A-9C show alternative electrical connections between an electrode (e.g., an electrode on an exterior surface of a carrier that forms part of a housing of an electronic device) and an electrical contact interior to the electronic device. In some examples, the carriers shown in cross-section in FIGS. 9A-9C may have circular perimeters. In other examples, the carriers may have perimeters that are oval-shaped, square-shaped, rectangular-shaped, and so on. The techniques described with reference to FIGS. 9A-9C can be applied to carriers having various perimeter shapes, to carriers having different compositions, and so on. In some embodiments, the features shown in FIGS. 9-9C may be replicated to electrically connect more than one electrode on an exterior surface of an electronic device to components interior to the electronic device.

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In FIG. 9A, the electrode 900 may be a thin film electrode that is PVD deposited on a surface 902 of a carrier 904. The surface 902 on which the electrode 900 is deposited may be a surface of the carrier 904 that is exterior to an electronic device (i.e., the electrode 900 may be deposited on an exterior surface 902 of the carrier 904). As shown, a conductive material used to form the electrode 900 may be deposited on the carrier 904 such that the material wraps around an edge 906 or perimeter of the carrier 904 to form an electrical contact 908 on a surface 910 of the carrier 904 that is interior to the electronic device (i.e., on an interior surface 910 of the carrier 904). In some cases, the electrical contact 908 may be a tab that traces a much smaller arc about the periphery of the carrier 904 than the electrode 900 (as shown, for example, in FIGS. 5C, 5D, and 5E). In other cases, the electrical contact 908 may be arc-shaped and trace an arc that is similar in size to an arc traced by the electrode 900 on the exterior surface 902 of the carrier 904.

In some cases, the conductive material(s) used to form the electrode 900 and electrical contact 908 may be deposited on the exterior surface 902, edge 906, and interior surface 910 of the carrier 904 in a single operation (or single set of operations in which the material(s) are deposited on the exterior surface 902, edge 906, and interior surface 910 of the carrier 904). In other cases, the material(s) used to form the electrode 900 may be deposited on the edge 906 or interior surface 910 of the carrier 904 in operations that are performed separately from one or more operations in which the electrode 900 is deposited on the exterior surface 902 of the carrier 904. In these latter examples, the material(s) may be deposited such that the materials overlap. In some cases, a set of one or more materials used to form the electrode 900 may differ from a set of one or more materials deposited on the edge 906 or interior surface 910 of the carrier 904.

In some embodiments, the conductive material(s) deposited on the exterior surface 902, edge 906, and interior surface 910 of the carrier 904 may include a layer of SUS or a layer of DLC. In other embodiments, only the electrode 900 or edge 906 of the carrier 904 may be coated with a layer of stainless steel or DLC. In some examples, the conductive material(s) may include a PVD deposited layer of AlTiN or CrSiCN.

In some embodiments, one or more masks (e.g., one or more ink masks) may be applied to the interior surface of the carrier (e.g., as described with reference to FIGS. 5A-5E, 6, & 7). In these embodiments, one or more of the conductive materials used to form the electrode 900 and electrical contact 908 may be applied over the mask(s). The conductive material(s), and the manner in which the conductive material(s) are deposited on the carrier 904, may therefore be selected to ensure adhesion of the conductive material(s) to the carrier 904 and to the ink or other material used to form the mask(s).

As shown in FIG. 9A, a peripheral band of the interior surface 910 of the carrier 904 may be attached to a recessed ledge 912 in another housing member 914 of the electronic device (e.g., with the carrier 904 overlapping the housing member 914). In such an embodiment, the carrier 904 may be attached to the housing member 914 using an adhesive 916, such as a heat-activated film (HAF). The adhesive 916 or conductive material(s), and the manner in which the carrier 904 is attached to the housing member 914, may therefore be selected to ensure adhesion of the carrier 904 to the housing member 914.

The electrical contact 908 may have a great enough width (e.g., a great enough width along a radius of the carrier 904) that the electrical contact 908 extends past the recessed

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ledge 912 in the housing member 914 when the carrier 904 is attached to the housing member 914, making the electrical contact 908 accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrical contact 908, to enable a signal to be received from or applied to the electrode 900.

In FIG. 9B, the electrode 918 may be a thin film electrode that is PVD deposited on a surface 920 of a carrier 922. The surface 920 on which the electrode 918 is deposited may be a surface of the carrier 922 that is exterior to an electronic device (i.e., the electrode 918 may be deposited on an exterior surface 920 of the carrier 922). Prior to or after depositing the electrode 918 on the carrier 922, a thru-carrier via 924 may be drilled or otherwise cut into the carrier 922. The thru-carrier via 924 may extend from the exterior surface 920 of the carrier 922 (or electrode 918) to the interior surface 926 of the carrier 922. The via 924 may be coated or filled with a conductive material 928 such as stainless steel (SUS), and the conductive material 928 may be covered by, overlap, or otherwise electrically connect to the electrode 918. In some cases, the conductive material 928 in the via 924 may be molded or glued in the via 924. The conductive material 928 may provide an electrical contact 930 on a surface 926 of the carrier 922 that is interior to an electronic device (i.e., on an interior surface of the carrier). In some cases, the conductive material 928 in the via 924 may overlap a portion of the interior surface 926 of the carrier 922, or may be connected to another conductive element deposited on the interior surface 926 of the carrier 922.

The conductive material(s) used to form the electrode 918 and deposited in the via 924 may be the same or different. In some embodiments, the conductive material(s) used to form the electrode 918 may include a layer of stainless steel (SUS) or a layer of diamond like carbon (DLC). In some examples, the conductive material(s) may include a PVD deposited layer of Aluminum Titanium Nitride (AlTiN) or Chromium Silicon Carbon Nitride (CrSiCN).

As shown in FIG. 9B, a peripheral band of the interior surface 926 of the carrier 922 may be attached to a recessed ledge 932 in another housing member 934 of the electronic device (e.g., with the carrier 922 overlapping the housing member 934). In such an embodiment, the carrier 922 may be attached to the housing member 934 using an adhesive 936, such as a HAF. The adhesive 936, and the manner in which the carrier 922 is attached to the housing member 934, may therefore be selected to ensure adhesion of the carrier 922 to the housing member 934.

When the carrier 922 is attached to the housing member 934, the via 924 may be positioned such that it overlaps the recessed ledge 932 or is interior to the recessed ledge 932, making the electrical contact 930 accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrical contact 930, to enable a signal to be received from or applied to the electrode 918.

In FIG. 9C, the electrode 938 may be a metallic arc-shaped element positioned between a carrier 940 and another housing member 942 of an electronic device. In some embodiments, the electrode 938 may be a singular metallic ring-shaped electrode (e.g., one electrode). In these embodiments, a peripheral band of a surface of the carrier 940 that is interior to the electronic device (e.g., an interior surface 944 of the carrier 940) may be attached to a recessed ledge 946 in the electrode 938 (e.g., with the carrier 940



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overlapping the electrode 938), and the electrode 938 may be attached to a recessed ledge 950 in the housing member 942 (e.g., with the electrode 938 overlapping the housing member 942). In other embodiments, the electrode 938 may be arc-shaped and may be one of two or more arc-shaped electrodes between the carrier 940 and the housing member 942. In these embodiments, a peripheral band of the interior surface of the carrier 940 may be attached to recessed ledges 946 in multiple arc-shaped electrodes 938 (e.g., with the carrier 940 overlapping the electrodes 938), and each of the arc-shaped electrodes 938 may be attached to the recessed ledge 950 in the housing member 942 (e.g., with the electrodes 938 overlapping the housing member 942). In some cases, the multiple arc-shaped electrodes 938 may be electrically isolated from each other by flexible seals or gaskets, or by rigid separators (e.g., rigid extensions of the housing member 942, which rigid extensions may include extensions of the recessed ledge 950 to which the electrodes 938 are attached. In some cases, the electrode 938 may be attached to the housing member 942 before the carrier 940 is attached to the electrode 938.

The electrode 938 may be formed of a conductive material including a layer of stainless steel (SUS) or DLC. In some examples, the conductive material may include a PVD deposited layer of Aluminum Titanium Nitride (AlTiN) or Chromium Silicon Carbon Nitride (CrSiCN). A surface 954 of the electrode 938 interior to the electronic device may provide an electrical contact for connecting components interior to the electronic device to the electrode 938.

In some cases, an edge 956 or perimeter of the carrier 940 may be abutted directly to the electrode 938, and an edge 958 of the electrode 938 may be abutted directly to the housing member 942. In other cases, an adhesive, seal, gasket, or filler may fill a gap between the carrier 940 and the electrode 938 or a gap between the electrode 938 and the housing member 942.

As shown in FIG. 9C, a peripheral band of the interior surface 944 of the carrier 940 may be attached to a recessed ledge 946 in the electrode 938, and a peripheral band of an interior surface 954 of the electrode 938 may be attached to the housing member 942. In such an embodiment, the carrier 940 may be attached to the electrode 938 or the electrode 938 may be attached to the housing member 942 using an adhesive 948 or 952, such as a HAF. The adhesive 948 or 952, and manner in which the respective elements are attached, may therefore be selected to ensure adhesion of the carrier 940 to the electrode 938 (or adhesion of the electrode 938 to the housing member 942).

When the electrode 938 is attached to the housing member 942, the electrode 938 may be positioned such that it overlaps the recessed ledge 950 or is interior to the recessed ledge 950, making the electrode 938 accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrode 938, to enable a signal to be received from or applied to the electrode 938.

FIGS. 10A-10D show alternative carrier profiles, and alternative attachments (e.g., structural attachments) of carriers to other housing members of an electronic device. In some examples, the carriers may have circular perimeters. In other examples, the carriers may have perimeters that are oval-shaped, square-shaped, rectangular-shaped, and so on. The techniques described with reference to FIGS. 10A-10D can be applied to carriers having various perimeter shapes, to carriers having different compositions, and so on. Each of FIGS. 10A-10D shows an exterior surface (e.g., a back

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surface) of an electronic device, such as an electronic watch, and a cross-section of the exterior surface of the electronic device.

In FIG. 10A, a carrier 1000 is attached to another housing member 1002 of an electronic device. The carrier 1000 includes an exterior surface 1004 that forms a part of the exterior surface of the electronic device, and an interior surface 1006 that faces components interior to the electronic device.

A peripheral band of the interior surface 1006 of the carrier 1000 may be attached to a recessed ledge 1064 in the housing member 1002 (e.g., with the carrier 1000 overlapping the housing member 1002). In such an embodiment, the carrier 1000 may be attached to the housing member 1002 using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier 1000 is attached to the housing member 1002, may be selected to ensure adhesion of the carrier 1000 to the housing member 1002.

The carrier 1000 may be variously configured, but in FIG. 10A, an inner portion 1008 of the interior surface 1006 of the carrier 1000, such as a portion of the carrier interior to a number of thru-carrier vias 1010, is flat. An outer portion 1012 of the interior surface 1006, such as a portion outside the number of thru-carrier vias 1010, is concave or inwardly-sloped (downwardly-sloped in the figure) with respect to the inner portion 1008 of the interior surface 1006. In contrast, the exterior surface 1004 of the carrier 1000 may be convex. Thus, the thickness of the carrier 1000 may vary to some degree from its center axis to its perimeter.

In some embodiments, one or more arc-shaped electrodes 1014 (e.g., two electrodes) may be positioned around the exterior surface 1004 of the carrier 1000, inward from the perimeter of the carrier 1000. In other embodiments, the electrodes 1014 may have other shapes or may extend to or around the perimeter. The electrodes 1014 may be PVD deposited thin film electrodes. In some cases, the electrodes 1014 may be connected to interior components of the electronic device by the thru-carrier vias 1010, which in some cases may be drilled or formed through the flat inner portion 1008 of the interior surface 1006 of the carrier 1000. In other cases, the electrodes 1014 may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier 1000, or in any of the ways shown in FIGS. 9A-9C.

In some cases, components such as a sensor subsystem may be attached to the inner, flat portion of the interior surface 1006 of the carrier 1000.

In FIG. 10B, a carrier 1016 is attached to another housing member 1018 of an electronic device. The carrier 1016 includes an exterior surface 1020 that forms a part of the exterior surface of the electronic device, and an interior surface 1022 that faces components interior to the electronic device.

A peripheral band of the interior surface 1022 of the carrier 1016 may be attached to a recessed ledge 1024 in the housing member 1018 (e.g., with the carrier 1016 overlapping the housing member 1018). In such an embodiment, the carrier 1016 may be attached to the housing member 1018 using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier 1016 is attached to the housing member 1018, may be selected to ensure adhesion of the carrier 1016 to the housing member 1018.

The carrier 1016 may be variously configured, but in FIG. 10B, the carrier 1016 has a uniform thickness. The interior surface 1022 of the carrier 1016 may be concave, and the exterior surface 1020 of the carrier 1016 may be convex. To provide a flat surface for connecting components (e.g., a

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sensor subsystem) to the carrier 1016, a secondary carrier 1026 having a convex exterior surface 1028 and a flat interior surface 1066 may be attached to an inner portion of the interior surface 1022 of the carrier 1016. The secondary (or interior) carrier 1026 may be attached to the primary (or exterior) carrier 1016 using a transparent adhesive. In some cases, the secondary carrier 1026 may be attached to the primary carrier 1016 interior to a number of thru-carrier vias 1030.

In some embodiments, one or more arc-shaped electrodes 1032 (e.g., two electrodes) may be positioned around the exterior surface of the carrier 1016, inward from the perimeter of the carrier 1016. In other embodiments, the electrodes 1032 may have other shapes or may extend to or around the perimeter. The electrodes 1032 may be PVD deposited thin film electrodes. In some cases, the electrodes 1032 may be connected to interior components of the electronic device by the thru-carrier vias 1030. In other cases, the electrodes 1032 may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier 1016, or in any of the ways shown in FIGS. 9A-9C.

FIGS. 10C & 10D each show a carrier attached to another housing member of an electronic device. The carrier includes an exterior surface that forms a part of the exterior surface of the electronic device, and an interior surface that faces components interior to the electronic device. In each of FIGS. 10C & 10D, the carrier has a flat interior surface and a convex exterior surface. The carriers shown in FIGS. 10C & 10D may be easier to manufacture than the carriers shown in FIGS. 10A & 10B.

In FIG. 10C, a carrier 1034 is attached to another housing member 1036 of an electronic device. The carrier 1034 includes an exterior surface 1038 that forms a part of the exterior surface of the electronic device, and an interior surface 1040 that faces components interior to the electronic device.

A peripheral band of the interior surface 1040 of the carrier 1034 may be attached to a recessed ledge 1042 in the housing member (e.g., with the carrier 1034 overlapping the housing member 1036). In such an embodiment, the carrier 1034 may be attached to the housing member 1036 using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier 1034 is attached to the housing member 1036, may be selected to ensure adhesion of the carrier 1034 to the housing member 1036.

In some embodiments, one or more arc-shaped electrodes 1044 (e.g., two electrodes) may be positioned around the perimeter of the exterior surface 1038 of the carrier 1034. In other embodiments, the electrodes 1044 may have other shapes or other positions on the exterior surface 1038 of the carrier 1034. The electrodes 1044 may be PVD deposited thin film electrodes. In some cases, the electrodes 1044 may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier 1034, or in any of the ways shown in FIGS. 9A-9C.

In some cases, components such as a sensor subsystem may be attached to the interior surface 1040 of the carrier 1034.

In FIG. 10D, a carrier 1060 is attached to another housing member 1046 of an electronic device (e.g., an electronic watch), similarly to how the carrier 1034 is attached to another housing member 1036 in FIG. 10C. For example, a peripheral band of the interior surface 1048 of the carrier 1060 may be attached to a recessed ledge 1050 in the housing member 1046 (e.g., with the carrier 1060 overlap-

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ping the housing member 1046). The carrier 1060 may be attached to the housing member 1046 using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier 1060 is attached to the housing member 1046, may be selected to ensure adhesion of the carrier 1060 to the housing member 1046.

The housing member 1046 to which the carrier 1060 is attached may be attached to yet another housing member (e.g., a second housing member 1052). A peripheral band of the interior surface 1054 of the first housing member 1046 may be attached to a recessed ledge 1056 in the second housing member 1052 (e.g., with the first housing member 1046 overlapping the second housing member 1052). The first housing member 1046 may be attached to the second housing member 1052 using an adhesive, such as a HAF. The adhesive, and the manner in which the first housing member 1046 is attached to the second housing member 1052, may be selected to ensure adhesion of the first housing member 1046 to the second housing member 1052. In some cases, the first housing member 1046 may electrically insulate the electrodes 1058 on the carrier 1060 from the second housing member 1052, or may provide a transition between incompatible materials, or may provide a support for the carrier 1060, or may facilitate assembly of the housing of the electronic device.

In some embodiments, one or more arc-shaped electrodes 1058 (e.g., two electrodes) may be positioned around the perimeter of the exterior surface of the carrier 1060. In other embodiments, the electrodes 1058 may have other shapes or other positions on the exterior surface 1062 of the carrier 1060. The electrodes 1058 may be PVD deposited thin film electrodes. In some cases, the electrodes 1058 may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier, or in any of the ways shown in FIGS. 9A-9C.

In some cases, components such as a sensor subsystem may be attached to the interior surface 1048 of the carrier 1060.

Turning now to the implementation of an electrode on a crown, FIG. 11A shows an example elevation of a crown assembly 1100. The crown assembly 1100 may be an example of a crown assembly included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. The crown assembly 1100 may include a crown 210.

The crown 210 may be mechanically and electrically connected to a shaft 1102 that extends through an opening in a housing. By way of example, the housing is shown to be the housing 206 of the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B. The crown 210 may be integrally formed from a single piece of material that includes the shaft 1102 (that is, they may be connected to one another), or the shaft 1102 may be semi-permanently attached to a crown body 1104 using a fastening means such as solder, threads, or an adhesive. The crown 210 (or at least the crown body 1104) may be external to the housing 206, and may be rotated and/or translated by a user of the electronic device incorporating the crown assembly 1100. Further, although the crown body 1104 and shaft 1102 are shown as integrally formed in FIGS. 11A and 11B, it should be appreciated that they may be separate pieces that are joined together.

The crown assembly 1100 may further include a shaft retainer 1106 receiving an end of the shaft 1102. The shaft retainer 1106 may be mechanically and/or electrically connected to the shaft 1102 (e.g., using solder, threads, or an



adhesive), interior to the housing 206. The shaft retainer 1106 may retain the crown 210 in position in relation to the housing 206.

One or more insulators 1108 (e.g., electrical insulators) may electrically insulate the crown 210 and/or shaft 1102 from the housing 206. The term “insulator” encompasses both a single insulator and multiple insulators taken as a set. The insulator 1108 is generally shown in FIG. 11 as an annular seal having an L-shaped profile, functioning as a collar for the shaft. The shaft 1102 and crown body 1104 may translate, moving toward and away from the housing 206 while the insulator 1108 and shaft retainer 1106 move with the shaft 1102. In some embodiments, the insulator 1108 may be stationary relative to the housing 206 while the shaft 1102, crown body 1104 and shaft retainer 1106 move.

The insulator 1108 or seal electrically insulates the shaft 1102 from the housing 206, and may also electrically insulate the housing 206 from the shaft retainer 1106. In some embodiments, the insulator 1108 may alternatively include more than one element and/or be positioned elsewhere within the crown assembly 1100. For example, the insulator 1108 may include an element, layer, or coating 1108a applied to a surface of the housing 206 that faces an underside of the crown 210, or to other elements that face the underside of the crown 210.

A tactile switch 1110 may be axially aligned with the shaft 1102 and positioned at an end of the shaft 1102 opposite the crown body 1104. By way of example, the tactile switch 1110 may be attached on a substrate 1112. The tactile switch 1110 may be actuated (e.g., switched between two or more states) as the shaft 1102 translates along an axis of the shaft 1102 to provide a crown input. A spring-biased conductor 1114 may be mechanically and electrically connected to at least one of the shaft 1102 or the shaft retainer 1106, and in FIG. 11 is shown to be connected to the shaft retainer 1106. The spring-biased conductor 1114 may be biased to electrically contact the shaft 1102 and/or shaft retainer 1106 during all phases of rotation and translation of the crown 210, and may electrically connect the shaft 1102 and/or shaft retainer 1106 to a circuit 1116 (e.g., a processor). When the crown is translated by a user, the spring-biased conductor 1114 may deform to maintain electrical contact with the shaft 1102 and/or shaft retainer 1106.

The crown assembly 1100 may further include an optical encoder 1118. The optical encoder 1118 may be used to detect rotation and/or translation of the shaft 1102 or shaft retainer 1106. In some embodiments, the circuit 1116 and optical encoder 1118 may be attached to the same substrate as the tactile switch 1110.

In some embodiments, the entirety of the crown 210 or crown body 1104 may be conductive and function as an electrode. The conductive crown body 1104 may be electrically connected to the circuit 1116 via the shaft 1102, shaft retainer 1106, and spring-biased conductor 1114. In other embodiments, only a portion of the crown 210 or crown body 1104 may be conductive and function as an electrode, and the conductive portion of the crown body 1104 may be electrically connected to the circuit 1116 via the shaft 1102, shaft retainer 1106, and spring-biased conductor 1114.

Because the signals received by or propagated from the crown 210 may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the crown 210 can have a significant impact on the ability of the circuit 1116 to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the crown assembly 1100. The materials,

positions, electrical connections to, and electrical routing paths for the crown assembly 1100 can also determine how well the crown assembly 1100 receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the crown 210 and internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the crown assembly 1100 operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator 1108 may be positioned to prevent moisture from electrically shorting the crown 210 to the housing 206, or the housing 206 may be grounded to provide electrical shielding for some or all of the signals propagated through the crown assembly 1100, or the interfaces between the shaft 1102 and the shaft retainer 1106, or between the shaft retainer 1106 and the spring-biased conductor 1114, may be configured to increase SNR and reduce signal attenuation.

In some embodiments, the crown 210 may include a coating, layer, or the like 1120 (“coating 1120”) that electrically isolates the crown 210. The coating may thus function as, have similar properties to, and/or be made from the same or similar materials as, the insulator 1108. Generally, the coating 1120 prevents electrical connection between the crown 210 and the housing 206, for example when water is present in the space between the crown and housing.

In the absence of the coating 1120, water, sweat, or another conductor may electrically bridge or short the crown 210 to the housing 206, presuming both the crown and housing are made from (or incorporate) an electrical conductor such as metal. In the event the crown 210 or some portion thereof serves as an electrode for measuring an electrocardiogram, shorting the crown 210 to the housing 206 (and thus to the skin of a wearer) may render the crown inoperable or the electrocardiogram unreliable.

The coating 1120 serves as a barrier against shorting the crown 210 to the housing 206 or other electrically conductive material or body, thereby ensuring the electrical functionality of the crown 210. In some embodiments the coating 1120 coats only those surfaces of the crown that oppose or face the housing; in other embodiments and as shown in FIG. 11A, the coating 1108a may extend across one or more sides of the crown 210. Further, the coating 1120 may extend onto a top or outer surface of the crown 210 (e.g., the surface of the crown that does not oppose or face the housing 206), although typically at least a portion of the outer surface is not covered by the coating in order to define an area of the crown that can electrically couple to a wearer's finger.

The coating 1120 also may extend at least partly down a shaft of the crown 210, as discussed in more detail with respect to FIG. 11B.

In some embodiments, a second coating 1122 may be applied to the housing 206 instead of, or in addition to, the coating 1120 on the crown 210. This housing coating 1122 serves the same function as the crown coating 1120, namely electrically insulating the housing 206 from the crown 210 when water or other electrical conductors are in the gap between the housing and crown. The housing coating 1122 may extend across the insulator 1108 (or a non-insulating collar), in some embodiments. Likewise, the housing coating 1122 may extend between the housing 206 and insulator 1108 in some embodiments, or may be an extension of the insulator.

In some embodiments, the coatings 1120, 1122 may improve wear or provide a cosmetic function (e.g., provide an accent or visually conceal a surface of the shaft, crown,

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and/or housing) for the crown assembly 1100. Alternatively, the housing 206, or that portion of the housing 206 that faces the crown 210, may be formed from a material that operates as an electrical insulator (e.g., plastic, ceramic, or the like). In some embodiments, one or more of the insulators 1108 (including element, layer, or coating 1108a or 1120) may be overmolded liquid crystal polymer (LCP) elements or coatings, which can provide very good separation resistance (high separation resistance) between moving or other parts. LCP layers may also be used in place of polyimide layers in flex circuits and other elements, and may not require the use of temperature or moisture-sensitive adhesives. LCP elements, layers, and coatings absorb less moisture than polyimides in high temperature and high humidity environments, which can be useful in maintaining high separation resistance between components when sensing low voltage signals (e.g., biometric signals of a person) under varying conditions (e.g., under non-controlled conditions outside a doctor's office or hospital). LCP elements, layers, and coatings also maintain good separation resistance high temperatures. Other elements, layers, or coatings that may be used to provide electrical isolation include silicone or acrylic elements, layers, or coatings, or other elements having a high surface resistance. Other examples of insulators or insulator positions are described with reference to FIGS. 11B, 12A, 12B, 13, & 14.

FIG. 11B shows another example crown 210 extending through a housing 206 of an electronic watch. As with other embodiments described herein, the crown 210 may be used to provide multiple types of input. For example, the crown may rotate about an axis of rotation (typically extending along a center length of the shaft 1102, from an exterior of the housing 206 to an interior of the housing) to provide a first type of crown input, translate along the axis of rotation (e.g., move towards and/or away from the housing 206) to provide a second type of crown input, and be touch-sensitive to provide a third type of crown input. The first and second types of input may control graphical output on the electronic watch's display, as described below in more detail with respect to FIGS. 26A-28B. The third type of input may be a measurement of an electrical signal (such as voltage, capacitance, current, or the like), or facilitating measurements of a differential in an electrical signal, to provide an ECG of a user. That is and as discussed in greater detail herein, the third type of input may be the crown 210 functioning as one of two electrodes in an electrical circuit configured to measure a user's ECG. Typically, although not necessarily, the second electrode is positioned a back of the electronic watch. This second electrode and its functionality is discussed in more detail elsewhere in this document.

The crown 210 may be formed from multiple elements attached together, as discussed in more detail below, or may be a single piece and connected to one another. The crown 210 generally includes a crown body 1104 coupled to (or formed with) a shaft 1102. The shaft 1102 of the crown may extend through the housing 206 and is typically received in, or passes through, a collar 1124. The collar 1124 may restrict tilting of the shaft 1102 and crown body 1104. Further, the collar 1124 may permit translation of the shaft 1102 and crown body 1104 toward and away from the housing and rotation of the shaft and crown body 1104 about the axis of rotation. The collar 1124 may be the same as, or similar to, the shaft retainer 1106 and/or insulator 1108 of FIG. 11A.

One or more O-rings 1134 are fitted about the shaft 1102 and within the collar 1124. The O-rings 1134 may be received within grooves, depressions, or the like within one or both of the shaft 1102 and collar 1124. The O-rings form

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a watertight seal and likewise reduce or eliminate contaminants passing into an interior of the housing 206 through the gap 1136 between the crown 210 and housing 206. The O-rings 1134 may also permit the shaft to rotate and/or translate while restricting (or helping to restrict) how far the shaft 1102 translates.

As with the embodiment shown in FIG. 11A, the crown 210 may short to the housing 206 if water or another conductor is present in the gap 1136 between the crown and housing and the two are not electrically insulated from one another. Shorting the crown 210 to the housing 206 results in the electronic watch unreliably measuring and displaying an ECG of a user or not functioning at all.

Accordingly and similar to the embodiment of FIG. 11A, an underside of the crown 210 may be coated with an electrically insulating coating 1132. The coating 1132 may prevent water or another contaminant from acting as a short or ground path between the crown 210 and housing 206. As discussed with respect to FIG. 11A and shown in that figure, such a coating may be applied to the housing 206 in addition to, or instead of, the crown 210.

The crown 210 shown in FIG. 11B is not formed from a single piece of material but instead is formed from multiple elements. The crown body 1104 and shaft 1102 may be formed from or as a single piece of material, for example metal or another suitable conductor, and provide an electrical path between an object touching the crown body 1104 and a sensor within the housing 206, such as the third sensor 230 discussed above. An insulating split 1146 may separate the crown body from a trim 1148; the trim 1148 may be annular, square, or any other suitable shape. The trim and split 1146 may provide various aesthetic looks as well as functional properties, such as different wear resistance, environmental resistance, and the like as compared to the crown body 1104. Accordingly, the trim 1148 may be made from the same material or a different material as the crown body 1104 and the shaft 1102.

Insofar as the split 1146 is an electrical insulator, the coating 1132 need not extend across the split or onto any portion of the trim 1148 (although it can in some embodiments). Thus, the coating 1132 may stop at an edge of the crown body 1104 abutting the split 1146. This may reduce manufacturing and assembly complexity of embodiments, as well as provide cost savings.

In addition to, or instead of, providing a coating 1132 on the crown 210 or housing 206, the collar 1124 may be coated. For example, an electrically insulating coating 1126 may be deposited on the collar 1124 and serve to electrically insulate the collar from the housing 206 and/or crown 210. This may be useful when the collar is made from an electrically conductive material and the crown 210 may be shorted to the collar 1124, in addition to or instead of to the housing 206.

As one non-limiting example, capillary action may retain water (or another liquid) in a portion of the gap between the collar 1124 and crown 210 while the part of the gap 1136 between the crown and housing 206 is sized to permit water to drain out. Thus, in such an embodiment the crown 210 may be at risk of electrically shorting to the collar 1124 but not the housing 206. It should be appreciated that in some embodiments the housing 206 and/or crown 210 may be coated as well as the collar 1124. It should likewise be appreciated that any or all of the electrically insulating coatings described herein may attenuate noise with respect to a signal conducted from the crown body 1104 through the



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shaft 1102 to a sensor, thereby providing more accurate and/or faster readings of a biological parameter such as an ECG.

Although the coating 1126 (and coating 1132) has been discussed as an electrical insulator, it should be appreciated that the coating(s) may provide other properties in addition to, or instead of, electrical insulation. For example, the coating 1126 may reduce friction between the collar 1124 and shaft 1102 as the shaft 1102 rotates and/or translates. The coating 1126 may reduce wear on either or both of the collar 1124 and shaft 1102 as another example.

Further, in some embodiments the gap 1136 between the crown 210 and housing 206 may be large enough that the collar 1124 may be visible. In order to obscure the first collar coating and/or the collar, a second collar coating 1128 may be applied over the first, insulating collar coating 1126. The second collar coating 1128 may be darker or otherwise visually conceal the first collar coating 1128 and collar 1124 from the naked eye.

As yet another option, the second coating 1128 may also provide environmental resistance and/or resist wear, tear, and/or friction between the collar 1124 and shaft 1102, as described above. Thus, the first collar coating 1126 may be an electrical insulator while the second collar coating 1128 may be chosen for its other material properties and/or resistances. Similarly, the first collar coating may be chosen for its material properties and/or resistances (including functioning as an electrical insulator) and the second collar coating may be used to obscure the first collar coating.

Any or all of the coatings described herein may be deposited in a number of ways, including electrophoretic deposition or other manners that are suitable and known in the art. Likewise, any or all of the coatings may incorporate materials such as titanium dioxide, Teflon, or the like to provide or enhance properties such as resistance to wear, lowering of friction between adjacent elements, and the like. In some embodiments the first collar coating 1126 (or any other coating) may be approximately 10-30 microns thick or even 5-50 microns. The second collar coating 1128 (or any other coating) may be thinner on the order of 3-5 microns or even 2-10 microns.

More detailed examples of the crown assembly 1100 described with reference to FIG. 11A are shown in FIGS. 12A, 12B, 13, & 14.

Turning now to FIGS. 12A & 12B, there is shown an example of a crown assembly 1200, as may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. FIG. 12A shows an exploded view of the crown assembly 1200, and FIG. 12B shows an assembled cross-section of the crown assembly 1200, as viewed from the front or rear face of an electronic device such as the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B.

The crown assembly 1200 is an example of the crown assembly 1100 shown in FIG. 11, and includes components corresponding to the crown 210, shaft retainer 1106, insulator 1108, tactile switch 1110, substrate 1112, spring-biased conductor 1114, circuit 1116, and optical encoder 1118.

The crown assembly 1200 may include a conductive rotatable shaft 1202 configured to extend through an opening in a housing 1242 (see FIG. 12B), such as the housing described with reference to FIG. 2A, 2C, 3, 4A, 4B, or 11. A user-rotatable crown 1204 may be mechanically attached to the shaft 1202 exterior to the housing 1242. The crown 1204 may be rotated by a user of an electronic watch, to in turn rotate the shaft 1202. In some cases, the crown 1204 may also be pulled or pushed by the user to translate the

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shaft 1202 along its axis. The crown 1204 may be electrically connected to a circuit within the housing 1242, but electrically isolated from the housing 1242.

The crown 1204 may be electrically connected to the shaft 1202. In some cases, at least part of the crown 1204 and at least part of the shaft 1202 may be molded, machined, or otherwise formed together (e.g., from a same material, such as a conductive ceramic or stainless steel).

In some embodiments, the crown 1204 may be formed of a conductive ceramic or stainless steel (or have a conductive ceramic or stainless steel core). The core may be coated in a PVD deposited layer of SUS or DLC, or an electro-deposited (ED) layer of AlTiN or CrSiCN, and may function as an electrode. In some embodiments, the crown 1204 may have a conductive crown body 1244 surrounded by a ring 1246 of non-conductive material (or other insulator). See, FIG. 12B. The non-conductive ring 1246 may help prevent shorting of the crown 1204 to the housing 1242. The ring 1246 of non-conductive material may in some cases be surrounded by another ring 1248 of conductive material. In the configuration shown, the ring 1248 may optionally contact and electrically short to a grounded housing 1242 when the crown is pressed, thereby helping to electrically shield the conductive crown body 1244 of the crown 1204 from some sources of interference. In some embodiments, the crown 1204 may have a conductive surface covered by a thin non-conductive coating. The non-conductive coating may provide a dielectric for capacitive coupling between the conductive surface and skin of a user of the crown 1204 (or an electronic watch or other device that includes the crown assembly 1200). In the same or different embodiments, the crown 1204 may have a non-conductive coating on a surface of the crown 1204 facing the housing 1242.

A shaft retainer 1206 may be mechanically connected to the shaft 1202, interior to the housing 1242 (e.g., interior to a watch body housing), after the shaft is inserted through the opening in the housing 1242 with the crown 1204 positioned exterior to the housing 1242. In some cases, the shaft retainer 1206 may include a nut, and the shaft 1202 may have a threaded male portion that engages a threaded female portion of the nut. In some cases, the shaft retainer 1206 may be conductive, or have a conductive coating thereon, and mechanical connection of the shaft retainer 1206 to the shaft 1202 may form an electrical connection between the shaft retainer 1206 and the shaft 1202. In an alternative embodiment (not shown), the shaft retainer 1206 may be integrally formed with the shaft 1202, and the shaft 1202 may be inserted through the opening in the housing 1242 from inside the housing 1242 and then attached to the crown 1204 (e.g., the crown 1204 may screw onto the shaft 1202).

In some embodiments, a collar 1208 may be aligned with the opening in the housing 1242, and a collar retainer 1210 may be coupled to the collar 1208 to retain the collar 1208 to the housing 1242 from a side of the housing 1242 opposite a side of the housing 1242 in which the collar 1208 is inserted. In some embodiments, the collar retainer 1210 may be coupled to the collar 1208 via threads on a male portion of the collar 1208 and corresponding threads on a female portion of the collar retainer 1210. Optionally, a gasket 1212 (e.g., an I-ring) made of a synthetic rubber and fluoropolymer elastomer (e.g., Viton), silicone, or another compressible material may be placed over the collar 1208 prior to insertion of the collar 1208 through the opening, and attachment of the collar retainer 1210 to the collar 1208 may compress the gasket 1212. The compressed gasket 1212 may provide stability to the collar 1208 and collar retainer 1210, or provide a moisture barrier between the collar 1208 and the

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housing 1242. The collar 1208 and collar retainer 1210 may be attached to one another, and thereby to the housing 1242, prior to insertion of the shaft 1202 through the collar 1208. Another gasket 1214 (e.g., a Y-ring) made of Viton, silicone, or another compressible material may be placed over the collar 1208, before or after insertion of the collar 1208 through the opening, but before the shaft 1202 is inserted through the collar 1208. The second gasket 1214 may provide a moisture barrier between the crown 1204 and the housing 1242 or the crown 1204 and the collar 1208.

Also prior to inserting the shaft 1202 through the collar 1208, and in some cases prior to inserting the collar 1208 into the opening in the housing 1242, an insulator 1216 may be inserted into or deposited on the interior of the collar 1208, or placed around or deposited on the shaft 1202. The insulator 1216 may also be inserted, placed, or deposited as the shaft 1202 is inserted into the collar 1208. In some cases, the insulator 1216 may include a non-conductive sleeve or bushing (e.g., a plastic sleeve) inserted (e.g., press-fit) into the collar 1208 (e.g., into a portion of the collar 1208 positioned interior to the housing 1242). The insulator 1216 may also or alternatively include a non-conductive sleeve overmolded on the collar (e.g., molded within the opening in the collar 1208 and over a surface of the collar 1208 facing the crown 1204). In some cases, the insulator 1216 may be an overmolded liquid crystal polymer (LCP) insulator 1216. The insulator 1216 may also or alternatively include a non-conductive coating on the collar 1208 (e.g., on an inner surface of the collar 1208), or a non-conductive coating on the shaft 1202, or a set of one or more non-conductive gaskets surrounding the shaft 1202. When the shaft 1202 is inserted into the collar 1208, the insulator 1216 may be positioned between the shaft 1202 and the collar 1208 and help to insulate a conductive portion of the shaft 1202 (or the entire shaft 1202) from the collar 1208.

Another insulator 1218 may be positioned between the shaft retainer 1206 and the collar retainer 1210. For example, a non-conductive (e.g., plastic) washer, plate, or shim may be attached to the interior of the collar retainer 1210, between the shaft retainer 1206 and the collar retainer 1210. In some cases, the non-conductive washer may be carried by a plate 1220, such as a plate formed of stainless steel (e.g., the insulator 1218 may be an overmolded LCP insulator 1218). In these cases, the non-conductive washer may be attached to the interior of the collar retainer 1210 by welding (e.g., laser welding) the plate 1220 to the collar retainer 1210. The non-conductive washer or other element may provide a bearing surface for the shaft retainer 1206.

As shown in FIGS. 12A & 12B, one or more O-rings 1222, 1224 or other gaskets may be placed over the shaft 1202 before the shaft 1202 is inserted into the collar 1208. The O-rings 1222, 1224 may be formed of a synthetic rubber, fluoropolymer elastomer, silicone, or another compressible material. The O-rings 1222, 1224 may maintain the shaft 1202 in a position that is centered within the collar 1208. In some cases, the O-rings 1222, 1224 may provide a seal between the shaft 1202 and the collar 1208. The O-rings 1222, 1224 may also function as an insulator between the shaft 1202 and the collar 1208. In some embodiments, the O-rings 1222, 1224 may be fitted to recesses in the shaft 1202. Additionally, a low-friction ring 1306 or filler may be placed around the top of the collar 1208, between the crown 1204 and the collar 1208. Alternatively, the low-friction ring 1250 or filler may be attached to the crown 1204, between the crown 1204 and the collar 1208. In some embodiments,

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the shaft 1202 may be smooth (not shown) and rotate within a thicker or closer fitting insulator 1216 without use of the O-rings 1222, 1224.

In some embodiments, a bracket 1226 may be attached (e.g., laser welded) to the collar retainer 1210 or another element within the housing 1242. The bracket 1226 may support a spring-biased conductor 1228 and maintain the spring-biased conductor 1228 in mechanical and electrical contact with the shaft retainer 1206 (or in some cases with an end of the shaft 1202, such as when the shaft extends through the shaft retainer (not shown)). As shown, the spring-biased conductor 1228 may include a shear plate that is spring-biased about an axis 1238, which axis 1238 is perpendicular to and radially outward from a second axis 1240 of the shaft 1202. By way of example, the shear plate is shown to be circular, although the shear plate could also have other shapes. In some embodiments, the surface of the shear plate that abuts the shaft retainer 1206 or shaft end may be hardened (e.g., with a PVD deposited coating of cobalt chromium (CoCr or hard chromium)) to mitigate the likelihood of the shaft retainer 1206 or shaft end wearing through the shear plate after multiple rotations or translations of the shaft 1202. The shear plate (and in some cases the entirety of the spring-biased conductor 1228) may be plated with gold or another material to improve electrical conductivity (e.g., prior to coating the shear plate with a hardener). In some cases, the spring-biased conductor 1228 may be formed (e.g., stamped or bent) from a piece of metal (e.g., stainless steel). In other cases, the spring-biased conductor 1228 may be formed in other ways. The length and thickness of the shear plate, perpendicular to the axis of the shaft 1202, can be optimized to provide a balance between a high enough spring constant to ensure good electrical contact between the shear plate and the shaft retainer 1206 or shaft end (even during rotation of the shaft 1202), on one hand, and a low enough spring constant to mitigate the likelihood that the shaft retainer 1206 or shaft end will wear through the shear plate (or through a coating thereon). A flat or relatively flat shear plate can reduce the dimension of the crown assembly 1200 along the axis 1240 of the shaft 1202.

In some embodiments, a majority or entirety of the shaft 1202, shaft retainer 1206, or crown 1204 may be coated with a non-conductive coating, but for an external conductive surface of the crown 1204 and a portion of the shaft 1202 or shaft retainer 1206 that contacts the spring-biased conductor 1228.

When the shaft 1202 is translatable, translation of the shaft 1202 into the housing 1242 (e.g., into the housing of a watch body) may cause the spring-biased conductor 1228 (or the shear plate thereof) to deform. However, the spring bias of the spring-biased conductor 1228 may cause the spring-biased conductor 1228 (or the shear plate thereof) to maintain electrical contact with the shaft retainer or shaft end, regardless of whether the shaft 1202 is in a first position or a second position with reference to translation of the shaft 1202. The spring-biased conductor 1228 may be electrically connected to a circuit, such as a circuit formed on or in a substrate 1230 such as a flex circuit or printed circuit board (PCB). In some cases, the spring-biased conductor 1228 may be surface-attached to the circuit substrate 1230 (such as soldered or otherwise mechanically connected, for example by using a surface-mount technology process), which circuit substrate 1230 may be supported by the rigid support member (or sub-housing frame member) 1226. A conductive grease may be deposited between the shaft retainer 1206 or shaft 1202 and the shear plate or other member of the spring-biased conductor 1228. The circuit



may be in electrical communication with the crown 1204 via the spring-biased conductor 1228, the shaft retainer 1206, and the shaft 1202 (or when an end of the shaft 1202 protrudes through the shaft retainer 1206, the circuit may be in electrical communication with the crown 1204 via the spring-biased conductor 1228 and the shaft 1202).

A tactile (tac) switch 1252, such as a dome switch, may be electrically connected to the circuit and mechanically connected to the circuit substrate 1230. In some cases, the tac switch 1252 may be surface-attached to the circuit substrate 1230 (such as soldered or otherwise mechanically connected). The shear plate of the spring-biased conductor 1228 may be positioned between the shaft retainer 1206 and the tac switch 1252. The tac switch 1252 may be actuated or change state in response to translation of the shaft 1202. Thus, when a user presses on the crown 1204, the shaft 1202 may translate into the housing 1242 (e.g., into the housing of a watch body) and actuate the tac switch 1252, placing the tac switch 1252 in one of a number of states. When the user releases pressure on the crown 1204 or pulls the crown 1204 outward from the housing 1242, the tac switch 1252 may retain the state in which it was placed when pressed, or advance to another state, or toggle between two states, depending on the type or configuration of the tac switch 1252.

The circuit to which the tac switch 1252 and spring-biased conductor 1228 are electrically connected may be part of, or electrically connected to, one or more circuits that carry portions of an optical encoder 1232 and other circuit elements, such as an interface 1234 to the electrodes described with reference to FIGS. 5C, 5D, 5E, 6-8, 9A-9C, & 10A-10D, or a processor that receives and processes signals received from or provided to the crown 1204 or other electrodes. By way of example, FIG. 12A shows a circuit 1236 (e.g., a flex circuit or PCB) to which a set of one or more light emitters and light detectors of an optical encoder 1232 is connected. The light emitter(s) may illuminate an encoder pattern or other rotating portion of the optical encoder 1232, which encoder pattern or other rotating portion of the optical encoder 1232 may be carried on (e.g., formed on, printed on, etc.) the shaft retainer 1206. The light detector(s) may receive reflections of the light emitted by the light emitter(s), and a processor may determine a direction of rotation, speed of rotation, angular position, translation, or other state(s) of the crown 1204 and shaft 1202.

The spring-biased conductor 1228 may be connected to a processor. The processor may be attached or coupled to one or more of the circuits shown in FIG. 12A. The processor may determine whether a user is touching the crown 1204, or determine a biological parameter of the user based on a signal received from or provided to the user via the crown 1204, or determine other parameters based on signals received from or provided to the crown 1204. In some cases, the processor may operate the crown and electrodes described in FIGS. 5C, 5D, 5E, 6-8, 9A-9C, 10A-10D, 11, 12A, & 12B as an electrocardiogram and provide an ECG to a user of a watch including the crown and electrodes.

In an alternate embodiment of the crown assembly 1200 shown in FIGS. 12A & 12B, the spring-biased conductor 1228 may include a conductive brush that is biased to contact a side of the shaft 1202 or a side of the shaft retainer 1206. The conductive brush may maintain electrical contact with the shaft 1202 or shaft retainer 1206 through rotation or translation of the shaft 1202, and may be electrically connected to a circuit such as the circuit that supports the tac switch 1352.

FIG. 13 shows a cross-section of a crown assembly 1300 as viewed from an edge of a watch body (e.g., an edge to which a watch band might be attached). The crown assembly 1300 shown in FIG. 13 differs from the crown assembly 1200 shown in FIGS. 12A & 12B in that the crown 1302 has a somewhat different configuration. For example, the crown 1302 has a conductive crown body 1304 surrounded by a non-conductive ring 1306. The non-conductive ring 1306 may be attached to the conductive crown body 1304 by an adhesive 1308. Alternatively, the ring 1306 may be conductive, and may be insulated from the conductive crown body 1304 by the adhesive 1308 (e.g., when the adhesive 1308 is non-conductive) or electrically connected to the conductive crown body 1304 (e.g., when the adhesive 1308 is conductive).

As shown in FIG. 13, the crown assembly 1300 may be positioned adjacent a transparent cover 1310 (e.g., a carrier) under which a display may be attached, such that the display is at least partially or fully within the housing. In some cases, the display may be a touch-sensitive display. In some embodiments, the display may also be a force-sensitive display. FIG. 13 shows one example of a force sensor 1312 for a force-sensitive display, in which a compressible gasket 1314 is bounded by first and second capacitive plates 1316, 1318 and positioned between the carrier 1310 and the housing 1242.

FIG. 14 shows a cross-section of a crown assembly 1400, as may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. Similarly to the crown assemblies 1200 and 1300 shown in FIGS. 12A, 12B, & 13, the crown assembly 1400 is an example of the crown assembly 1100 shown in FIG. 11.

The crown assembly 1400 is similar to the crown assembly 1200 in that its crown 1402 has a conductive crown body 1404 surrounded by an inner ring 1406 of non-conductive material and an outer ring 1408 of conductive material. The conductive crown body 1404 may be formed of a conductive ceramic or stainless steel, and may be coated in a PVD deposited layer of SUS or DLC, or an ED layer of AlTiN or CrSiCN, and may function as an electrode. The non-conductive inner ring 1406 may help prevent shorting of the crown 1402 to the housing 1242, and may be formed of a plastic or elastomer, for example. The conductive outer ring 1408 may be formed of the same or different material(s) as the conductive crown body 1404.

The non-conductive inner ring 1406 may extend from an outer surface of the crown 1402 to under a portion of the conductive crown body 1404. In this manner, the non-conductive inner ring 1406 may prevent the conductive crown body 1404 from contacting the collar 1208 when the crown 1402 is translated toward the housing 1242.

The conductive outer ring 1408 may extend from an outer surface of the crown 1402 to under a portion of the non-conductive inner ring 1406. In this manner, if the housing 1242 is grounded and the conductive outer ring 1408 contacts the housing 1242, the conductive outer ring 1408 may be grounded to the housing 1242.

In contrast to the crown assemblies 1200 and 1300, the crown assembly 1400 has an insulator 1410 (e.g., a non-conductive element, layer, or coating) applied to at least one surface of the collar 1208 (e.g., to at least a portion of the surface or surfaces that face an underside of the conductive crown body 1404). The insulator 1410 may further prevent the conductive crown body 1404 from contacting the collar 1208 when the crown 1402 is translated toward the housing 1242 and may provide increased separation resistance between the collar 1208 and the crown 210. In some

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embodiments, the insulator 1410 may include a layer of plastic that is overmolded (e.g., LCP overmolded) on at least a portion (or all) of the collar 1208 that faces the crown 210 (or a plastic element that is placed over or adhered to at least a portion (or all) of the collar 1208, or a coating that is applied to at least a portion of the collar 1208). In some embodiments, the plastic may extend to adjacent surfaces of the housing 206, or into the central opening in the collar 1208. In some embodiments, the insulator 1410 may include a coating (e.g., an electro-deposited (ED) acrylic-based polymer coating). Alternatively or additionally, an insulator (e.g., an element, layer, or coating) may be applied to the underside of the conductive crown body 1404, or to surfaces of the shaft 1202 that face the collar 1208 and/or housing 206. Alternatively, the collar 1208 may be formed from plastic or another material that is non-conductive or otherwise electrically isolates the conductive crown body 1404 of the crown 1402, or the shaft 1202, from other conductive components of the crown assembly 1500.

In any of the crown assemblies 1200, 1300, 1400 described in the present disclosure, the crown 1204, 1302, or 1402 may alternately be a monolithic structure and not include additional conductive or non-conductive rings, or may include a single non-conductive (e.g., plastic) ring surrounding a conductive central portion.

Turning now to the implementation of an electrode on a button, FIG. 15 shows an example cross-section of a button assembly 1500. The button assembly 1500 may be an example of a button assembly included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B.

The button assembly 1500 may include a conductive button cap 1502. The conductive button cap 1502 may be retained within an opening in a housing by a button cap retention assembly 1504. The button cap retention assembly 1504, or parts thereof, may be conductive. By way of example, the housing is shown to be the housing 206 of the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B. The button cap retention assembly 1504 may be attached to the housing 206 and extend through the opening in the housing 206. In some embodiments, the button cap retention assembly 1504 may include a first component 1506 that is inserted through the opening from one side of the housing 206, and a second component 1508 that fastens to the first component 1506 on the other side of the housing 206 (e.g., by threads, screws, solder, or an adhesive).

A set of one or more insulators 1510 (e.g., electrical insulators) may electrically insulate the button cap retention assembly 1504 from the housing 206. The insulator 1510 may also electrically insulate the conductive button cap 1502 from the housing 206. Although the insulator 1510 is generally shown in FIG. 15 as a singular annular seal around the perimeter of the button assembly 1500, the insulator 1510 may alternatively include more than one element or be positioned elsewhere within the button assembly 1500, as described with reference to FIGS. 16A, 16B, 17A, 17B, 18A, & 18C.

The conductive button cap 1502 may translate toward and away from the housing 206, and may be in electrical contact with the button cap retention assembly 1504 during all phases of translation. When the conductive button cap 1502 is pressed by a user and translates toward the housing 206, a tactile switch 1512 may be actuated (e.g., switched between two or more states). A shaft 1514 may extend from an interior surface of, or be formed integrally with, the conductive button cap 1502 and a depressible surface of the

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tactile switch 1512. The tactile switch 1512 and shaft 1514, or other elements not shown in FIG. 15 (e.g., springs), may bias the conductive button cap 1502 in an outwardly translated position.

The conductive button cap 1502 may function as an electrode, and an electrical signal may be routed between the conductive button cap 1502 and a circuit 1516, at least in part, via the button cap retention assembly 1504. In some embodiments, the button cap retention assembly 1504, tactile switch 1512, and circuit 1516 may be attached to a common substrate 1518.

Because the signals received by or propagated from the conductive button cap 1502 may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the conductive button cap 1502 can have a significant impact on the ability of the circuit 1516 to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the button assembly 1500. The materials, positions, electrical connections to, and electrical routing paths for the button assembly 1500 can also determine how well the button assembly 1500 receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the conductive button cap 1502 and internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the button assembly 1500 operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator 1510 may be positioned to prevent moisture from electrically shorting the conductive button cap 1502 to the housing 206, or the housing 206 may be grounded to provide electrical shielding for some or all of the signals propagated through the button assembly 1500.

More detailed examples of the button assembly 1500 described with reference to FIG. 15 are shown in FIGS. 16A, 16B, 17A, 17B, 18A, & 18B.

Turning now to FIGS. 16A & 16B, there is shown an example of a button assembly 1600 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. FIG. 16A shows an exploded view of the button assembly 1600, and FIG. 16B shows an assembled cross-section of the button assembly 1600, as viewed from the front or rear face of an electronic device such as the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, and 4B.

The button assembly 1600 is an example of the button assembly 1500 shown in FIG. 15, and includes components corresponding to the conductive button cap 1502, button cap retention assembly 1504, insulator 1510, and tactile switch 1512.

The button assembly 1600 may be at least partially within an opening 1602 in a housing 1604 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and attached to the housing or an internal structure. In some cases, and as shown, the housing 1604 may include a cavity 1606 (FIG. 16B) defined by a sidewall 1608 and a ledge 1610. The ledge 1610 may surround the opening 1602, and the sidewall 1608 may surround the ledge 1610.

The button assembly 1600 may include a conductive button cap 1612. The conductive button cap 1612 may be retained by a button cap retention assembly 1614, and may be translatable toward and away from the housing 1604. The button cap retention assembly 1614 may extend through the opening 1602 and be attached to the housing 1604. In some



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examples, the button cap retention assembly 1614 may include a bracket 1616 that overlaps the ledge 1610 interior to the housing 1604, and a retainer 1618 that overlaps the ledge 1610 exterior to the housing 1604. The retainer 1618 may be mechanically attached to the bracket 1616 by a set of screws 1620 or other mechanical fastener. The screws 1620 may be inserted into through-holes in the bracket 1616 and screwed into threaded holes in the retainer 1618, clamping the ledge 1610 between the bracket 1616 and the retainer 1618.

The conductive button cap 1612 may have an exterior surface 1622, a sidewall or set of sidewalls 1624 parallel to the sidewall 1608 of the cavity 1606, and an inward facing lip or set of lips 1626 (FIG. 16B) that extends between the retainer 1618 and the ledge 1610 and toward a center axis of the conductive button cap 1612. A set of one or more coil springs 1628 or other spring-biased members may be positioned between an outer surface of the retainer 1618 and an underside of the conductive button cap 1612, and may bias the conductive button cap 1612 in an outward state of translation.

The button cap retention assembly 1614, and in particular the retainer 1618, may have a through-hole 1629 defined therein, with an axis of the through-hole 1629 extending perpendicular to the opening 1602 in the housing 1604. A shaft 1630 may be positioned within the through-hole 1629, and may translate toward and away from the housing 1604. The shaft 1630 may be mechanically connected to the conductive button cap 1612, or may be biased to contact the conductive button cap 1612. By way of example, the shaft 1630 may be non-conductive. In a state of rest, the shaft 1630 and conductive button cap 1612 may be biased in an outward state of translation (i.e., away from the opening 1602) by the coil springs 1628 and/or a spring-biased tactile switch 1632. When a user presses the conductive button cap 1612 toward the housing 1604, the press may overcome the bias provided by the coil springs 1628 and/or tactile switch 1632, and pressure on the conductive button cap 1612 may be transferred to the shaft 1630, which translates toward the housing 1604 and presses on the tactile switch 1632 to change the state of the tactile switch 1632 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 1632 may be aligned with an axis of the shaft 1630 and attached to the bracket 1616 using an adhesive 1634 (e.g., a conductive PSA).

In some embodiments, a gasket 1636 (e.g., an O-ring) may be positioned between the shaft 1630 and the through-hole. The shaft 1630 may have a circumferential groove 1638 in which a portion of the gasket 1636 is seated so that the gasket 1636 moves in a predictable way in response to movement of the shaft 1630. In some examples, the gasket 1636 may be non-conductive.

The button assembly 1600 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly 1614 from the housing 1604, and electrically insulate the conductive button cap 1612 from the housing 1604. For example, the button assembly 1600 may include a first electrical insulator, such as a sleeve 1640 (or set of shims), positioned between the conductive button cap 1612 and the sidewall 1608 (or set of sidewalls) of the cavity 1606 in the housing 1604. In some cases, the sleeve 1640 may include a closed-shape sidewall and an inward facing lip 1642 (FIG. 16B). In other cases, the sleeve 1640 may not include the inward facing lip 1642 or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter

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gasket (e.g., an insulator including the lip 1642 but not the sidewall). A second electrical insulator may include an adhesive 1644 (e.g., an adhesive ring) applied to a surface of the retainer 1618 facing the housing 1604, or to the outer surface of the ledge 1610 within the cavity 1606. In some cases, the adhesive 1644 may include a PSA. A gasket or seal 1646, external to the housing 1604, may be bonded to the adhesive 1644. The adhesive 1644 and seal 1646 may be compressed when the screws 1620 are tightened to clamp the housing 1604 between the bracket 1616 and retainer 1618 of the button cap retention assembly 1614. A third electrical insulator may include a spacer 1648, internal to the housing 1604, positioned between the bracket 1616 and the housing 1604. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly 1614 (e.g., the bracket 1616 and the retainer 1618) from the housing 1604. The first electrical insulator may electrically insulate the conductive button cap 1612 from the housing 1604. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 1612 or button cap retention assembly 1614 from the housing 1604.

In use, a signal may be applied to, or received from, the button cap retention assembly 1614 (e.g., to/from the bracket 1616) via a circuit (e.g., a flex circuit or other circuit element 1650) that is electrically connected to the bracket 1616 (e.g., via a conductive adhesive 1652). A signal may travel through the conductive button cap 1612, coil springs 1628, retainer 1618, screws 1620, and bracket 1616 via a first electrical path, or through the conductive button cap 1612, retainer 1618, screws 1620, and bracket 1616 via a second electrical path. Although the second electrical path may be broken when the conductive button cap 1612 is pressed by a user, the conductive button cap 1612 may remain in electrical contact with the button cap retention assembly 1614 during all states of translation (e.g., via the first electrical path).

With reference to FIGS. 17A & 17B, there is shown another example of a button assembly 1700 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. FIG. 17A shows an exploded view of the button assembly 1700, and FIG. 17B shows an assembled cross-section of the button assembly 1700, as viewed from the front or rear face of an electronic device such as the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B.

The button assembly 1700 is an example of the button assembly 1500 shown in FIG. 15, and includes components corresponding to the conductive button cap 1502, button cap retention assembly 1504, insulator 1510, and tactile switch 1512.

The button assembly 1700 may be at least partially within an opening 1702 in a housing 1704 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and may be attached to any the housing or an internal structure. In some cases, and as shown, the housing 1704 may include a cavity 1706 (FIG. 17B) defined by at least one sidewall (e.g., a single sidewall 1708 or set of sidewalls) and a ledge 1710. The ledge 1710 may define the opening 1702, and the sidewall 1708 may surround the ledge 1710.

The button assembly 1700 may include a conductive button cap 1712 (or button cap having a conductive portion). The conductive button cap 1712 may be retained by a button cap retention assembly 1714 (or button retainer), and may be translatable toward and away from the housing 1704. The button cap retention assembly 1714 may extend through the

opening 1702 and be connected or otherwise attached to the housing 1704. In some examples, the button cap retention assembly 1714 may include a bracket 1716 that overlaps the ledge 1710 interior to the housing 1704, and a retainer 1718 that overlaps the ledge 1710 exterior to the housing 1704. The retainer 1718 may be mechanically attached to the bracket 1716 by a set of screws 1720 or other mechanical fastener. The screws 1720 may be inserted into through-holes in the bracket 1716 and screwed into threaded holes in the retainer 1718, clamping the ledge 1710 between the bracket 1716 and the retainer 1718.

The conductive button cap 1712 may have an exterior surface 1722, a sidewall or set of sidewalls 1724 parallel to the sidewall 1708 of the cavity 1706, and an inward facing lip or set of lips 1726 (FIG. 19) that extends between the retainer 1718 and the ledge 1710 and toward a center axis of the conductive button cap 1712. A set of one or more coil springs 1728 or other spring-biased members may be positioned between an outer surface of the retainer 1718 and an underside of the conductive button cap 1712, and may bias the conductive button cap 1712 in an outward state of translation.

The button cap retention assembly 1714, and in particular the retainer 1718, may have a through-hole 1729 defined therein, with an axis of the through-hole 1729 extending perpendicular to the opening 1702 in the housing 1704. A shaft 1730 may be positioned within the through-hole 1729, and may translate toward and away from the housing 1704. The shaft 1730 may be mechanically connected to the conductive button cap 1712, or may be biased to contact the conductive button cap 1712. In some cases, the shaft 1730 may be mechanically and electrically connected to the conductive button cap 1712. In a state of rest, the shaft 1730 and conductive button cap 1712 may be biased in an outward state of translation (i.e., away from the opening 1702) by the coil springs 1728 and/or a spring-biased tactile switch 1732. In some cases, a shim 1734, such as a non-conductive shim, may be attached to an end of the shaft 1730 facing the tactile switch 1732. When a user presses the conductive button cap 1712 toward the housing 1704, the press may overcome the bias provided by the coil springs 1728 and/or tactile switch 1732, and pressure on the conductive button cap 1712 may be transferred to the shaft 1730, which translates toward the housing 1704 and presses on the tactile switch 1732 to change the state of the tactile switch 1732 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 1732 may be aligned with an axis of the shaft 1730 and attached to the bracket 1716 using an adhesive 1736 (e.g., a conductive PSA).

In some embodiments, a gasket 1738 (e.g., an O-ring) may be positioned between the shaft 1730 and the through-hole. The shaft 1730 may have a circumferential groove 1740 (FIG. 17B) in which a portion of the gasket 1738 is seated so that the gasket 1738 moves in a predictable way in response to movement of the shaft 1730. In some examples, the gasket 1738 may be conductive.

The button assembly 1700 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly 1714 from the housing 1704, and electrically insulate the conductive button cap 1712 from the housing 1704. For example, the button assembly 1700 may include a first electrical insulator, such as a sleeve 1742 (or set of shims), positioned between the conductive button cap 1712 and the sidewall 1708 (or set of sidewalls) of the cavity 1706 in the housing 1704. In some cases, the sleeve 1742 may include a closed-shape sidewall

and an inward facing lip 1744 (FIG. 18B). In other cases, the sleeve 1742 may not include the inward facing lip 1744 or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter gasket (e.g., an insulator including the lip 1744 but not the sidewall). A second electrical insulator may include an adhesive 1746 (e.g., an adhesive ring) applied to a surface of the retainer 1718 facing the housing 1704, or to the outer surface of the ledge 1710 within the cavity 1706. In some cases, the adhesive 1746 may include a PSA. A gasket or seal 1748, external to the housing 1704, may be bonded to the adhesive 1746. The adhesive 1746 and seal 1748 may be compressed when the screws 1720 are tightened to clamp the housing 1704 between the bracket 1716 and retainer 1718 of the button cap retention assembly 1714. A third electrical insulator may include a spacer 1750, internal to the housing 1704, positioned between the bracket 1716 and the housing 1704. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly 1714 (e.g., the bracket 1716 and the retainer 1718) from the housing 1704. The first electrical insulator may electrically insulate the conductive button cap 1712 from the housing 1704. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 1712 or button cap retention assembly 1714 from the housing 1704.

In use, a signal may be applied to, or received from, the button cap retention assembly 1714 (e.g., to/from the bracket 1716) via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the bracket 1716 (e.g., as described with reference to FIG. 17A). A signal may travel through the conductive button cap 1712, shaft 1730, conductive gasket 1738, retainer 1718, screws 1720, and bracket 1716 via a first electrical path. The signal may also travel through the conductive button cap 1712, coil springs 1728, retainer 1718, screws 1720, and bracket 1716 via a second electrical path, or through the conductive button cap 1712, retainer 1718, screws 1720, and bracket 1716 via a third electrical path. Although the third electrical path may be broken when the conductive button cap 1712 is pressed by a user, the conductive button cap 1712 may remain in electrical contact with the button cap retention assembly 1714 during all states of translation (e.g., via the first and second electrical paths).

FIGS. 18A & 18B show another example of a button assembly 2000 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. FIG. 18A shows an exploded view of the button assembly 1800, and FIG. 18B shows an assembled cross-section of the button assembly 1800, as viewed from the front or rear face of an electronic device such as the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B.

The button assembly 1800 is an example of the button assembly 1500 shown in FIG. 15, and includes components corresponding to the conductive button cap 1502, button cap retention assembly 1504, insulator 1510, and tactile switch 1512.

The button assembly 1800 may be at least partially within an opening 1802 in a housing 1804 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing 1804 may include a cavity 1806 (FIG. 18B) defined by at least one sidewall (e.g., a single sidewall 1808 or set



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of sidewalls) and a ledge 1810. The ledge 1810 may define the opening 1802, and the sidewall 1808 may surround the ledge 1810.

The button assembly 1800 may include a conductive button cap 1812 (or button cap having a conductive portion). The conductive button cap 1812 may be retained by a button cap retention assembly 1814 (or button retainer), and may be translatable toward and away from the housing 1804. The button cap retention assembly 1814 may extend through the opening 1802 and be connected or otherwise attached to the housing 1804. In some examples, the button cap retention assembly 1814 may include a bracket 1816 that overlaps the ledge 1810 interior to the housing 1804, and a retainer 1818 that overlaps the ledge 1810 exterior to the housing 1804. The retainer 1818 may be mechanically attached to the bracket 1816 by a set of screws 1820 or other mechanical fastener. The screws 1820 may be inserted into through-holes in the bracket 1816 and screwed into threaded holes in the retainer 1818, clamping the ledge 1810 between the bracket 1816 and the retainer 1818.

The conductive button cap 1812 may have an exterior surface 1822, a sidewall or set of sidewalls 1824 parallel to the sidewall 1808 of the cavity 1806, and an inward facing lip or set of lips 1826 (FIG. 18B) that extends between the retainer 1818 and the ledge 1810 and toward a center axis of the conductive button cap 1812. A set of one or more coil springs 1828 or other spring-biased members may be positioned between an outer surface of the retainer 1818 and an underside of the conductive button cap 1812, and may bias the conductive button cap 1812 in an outward state of translation.

The button cap retention assembly 1814, and in particular the retainer 1818, may have a through-hole 1829 defined therein, with an axis of the through-hole 1829 extending perpendicular to the opening 1802 in the housing 1804. A shaft 1830 may be positioned within the through-hole 1829, and may translate toward and away from the housing 1804. The shaft 1830 may be mechanically connected to the conductive button cap 1812, or may be biased to contact the conductive button cap 1812. In some cases, the shaft 1830 may be mechanically and electrically connected to the conductive button cap 1812. In a state of rest, the shaft 1830 and conductive button cap 1812 may be biased in an outward state of translation (i.e., away from the opening 1802) by the coil springs 1828 and/or a spring-biased tactile switch 1832. In some cases, a spring-biased conductor (e.g., a conductive shear plate 1834) may extend between the tactile switch 1832 and an end of the shaft 1830 facing the tactile switch 1832. When a user presses the conductive button cap 1812 toward the housing 1804, the press may overcome the bias provided by the coil springs 1828 and/or tactile switch 1832, and pressure on the conductive button cap 1812 may be transferred to the shaft 1830, which translates toward the housing 1804 and presses on the tactile switch 1832 to change the state of the tactile switch 1832 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 1832 may be aligned with an axis of the shaft 1830 and attached to the bracket 1816 using an adhesive 1836 (e.g., a conductive PSA).

In some embodiments, a gasket 1838 (e.g., an O-ring) may be positioned between the shaft 1830 and the through-hole. The shaft 1830 may have a circumferential groove 1840 in which a portion of the gasket 1838 is seated so that the gasket 1838 moves in a predictable way in response to movement of the shaft 1830. In some examples, the gasket 1838 may be non-conductive.

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The button assembly 1800 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly 1814 from the housing 1804, and electrically insulate the conductive button cap 1812 from the housing 1804. For example, the button assembly 1800 may include a first electrical insulator, such as a sleeve 1842 (or set of shims), positioned between the conductive button cap 1812 and the sidewall 1808 (or set of sidewalls) of the cavity 1806 in the housing 1804. In some cases, the sleeve 1842 may include a closed-shape sidewall and an inward facing lip 1844 (FIG. 18B). In other cases, the sleeve 1842 may not include the inward facing lip 1844 or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter gasket (e.g., an insulator including the lip 1844 but not the sidewall). A second electrical insulator may include an adhesive 1846 (e.g., an adhesive ring) applied to a surface of the retainer 1818 facing the housing 1804, or to the outer surface of the ledge 1810 within the cavity 1806. In some cases, the adhesive 1846 may include a PSA. A gasket or seal 1848, external to the housing 1804, may be bonded to the adhesive 1846. The adhesive 1846 and seal 1848 may be compressed when the screws 1820 are tightened to clamp the housing 1804 between the bracket 1816 and retainer 1818 of the button cap retention assembly 1814. A third electrical insulator may include a spacer 1850, internal to the housing 1804, positioned between the bracket 1816 and the housing 1804. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly 1814 (e.g., the bracket 1816 and the retainer 1818) from the housing 1804. The first electrical insulator may electrically insulate the conductive button cap 1812 from the housing 1804. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 1812 or button cap retention assembly 1814 from the housing 1804.

The shear plate 1834 may be formed from a conductive sheet that is stamped, molded, or otherwise shaped to form an open (shown) or closed (not shown) shape conductive perimeter 1852 and an elevated tab 1854 (e.g., a tab having an end positioned in a different plane than the conductive perimeter 1852). The conductive perimeter 1852 may be positioned between the bracket 1816 and spacer 1850, such that the conductive perimeter 1852 and shear plate 1834 are electrically insulated from the housing 1804. The shear plate 1834 deforms in response to translation of the shaft 1830.

In use, a signal may be applied to, or received from, the button cap retention assembly 1814 (e.g., to/from the bracket 1816) via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the bracket 1816 (e.g., as described with reference to FIG. 16B). A signal may travel through the conductive button cap 1812, shaft 1830, shear plate 1834, and bracket 1816 via a first electrical path. The signal may also travel through the conductive button cap 1812, coil springs 1828, retainer 1818, screws 1820, and bracket 1816 via a second electrical path, or through the conductive button cap 1812, retainer 1818, screws 1820, and bracket 1816 via a third electrical path. Although the third electrical path may be broken when the conductive button cap 1812 is pressed by a user, the conductive button cap 1812 may remain in electrical contact with the button cap retention assembly 1814 during all states of translation (e.g., via the first and second electrical paths).

FIG. 19 shows an example elevation of a button assembly 1900. The button assembly 1900 may be an example of a



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button assembly included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B.

The button assembly 1900 may include a conductive button cap 1902. The conductive button cap 1902 may be retained within an opening in a housing by a button cap retention assembly 1904 (e.g., a button retainer). The button cap retention assembly 1904, or parts thereof, may be conductive. By way of example, the housing is shown to be the housing 206 of the watch body 202 described with reference to FIGS. 2A-2C, 3, 4A, & 4B. The button cap retention assembly 1904 may be attached to the housing 206 and extend through the opening in the housing 206. In some embodiments, the button cap retention assembly 1904 may include a first component 1906 that is inserted through the opening from one side of the housing 206, and a second component 1908 that fastens to the first component 1906 on the other side of the housing 206 (e.g., by threads, screws, solder, or an adhesive).

A set of one or more insulators 1910 (e.g., electrical insulators) may electrically insulate the conductive button cap 1902 from the button cap retention assembly 1904. The insulator 1910 may also electrically insulate the conductive button cap 1902 from the housing 206. Although the insulator 1910 is generally shown in FIG. 19 to include a non-conductive liner 1910a on an underside of the conductive button cap 1902, a non-conductive sleeve 1910b positioned between the conductive button cap 1902 and the housing 206, and a non-conductive sleeve 1910c positioned between the button cap retention assembly 1904 and a shaft 1914, the insulator 1910 may alternatively include more or fewer elements, which elements may be positioned in different locations within the button assembly 1900, as described with reference to FIGS. 20, 21, & 22.

The conductive button cap 1902 may translate toward and away from the housing 206, and may be insulated from the button cap retention assembly 1904 during all phases of translation. When the conductive button cap 1902 is pressed by a user and translates toward the housing 206, a tactile switch 1912 may be actuated (e.g., switched between two or more states). The shaft 1914 may extend between an interior surface of the conductive button cap 1902 and a depressible surface of the tactile switch 1912. The tactile switch 1912 and shaft 1914, or other elements not shown in FIG. 19 (e.g., springs), may bias the conductive button cap 1902 in an outwardly translated position.

The conductive button cap 1902 may function as an electrode, and an electrical signal may be routed between the conductive button cap 1902 and a circuit 1916, at least in part, via the shaft 1914. In some embodiments, the button cap retention assembly 1904, tactile switch 1912, and circuit 1916 may be attached to a common substrate 1918.

Because the signals received by or propagated from the conductive button cap 1902 may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the conductive button cap 1902 can have a significant impact on the ability of the circuit 1916 to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the button assembly 1900. The materials, positions, electrical connections to, and electrical routing paths for the button assembly 1900 can also determine how well the button assembly 1900 receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the conductive button cap 1902 and

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internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the button assembly 1900 operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator 1910 may be positioned to prevent moisture from electrically shorting the conductive button cap 1902 to the housing 206, or the housing 206 may be grounded to provide electrical shielding for some or all of the signals propagated through the button assembly 1900.

More detailed examples of the button assembly 1900 described with reference to FIG. 19 are shown in FIGS. 20, 21, & 22.

Referring now to FIG. 20, there is shown an assembled cross-section of another example of a button assembly 2000 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. The button assembly 2000 may be at least partially within an opening 2002 in a housing 2004 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing 2004 may include a cavity 2006 defined by at least one sidewall (e.g., a single sidewall 2008 or set of sidewalls) and a ledge 2010. The ledge 2010 may define the opening 2002, and the sidewall 2008 may surround the ledge 2010.

The button assembly 2000 may include a conductive button cap 2012 (or button cap having a conductive portion). The conductive button cap 2012 may be retained by a button cap retention assembly 2014 (or button retainer), and may be translatable toward and away from the housing 2004. The button cap retention assembly 2014 may extend through the opening 2002 and be connected or otherwise attached to the housing 2004. In some examples, the button cap retention assembly 2014 may include a bracket 2016 that overlaps the ledge 2010 interior to the housing 2004, and a retainer 2018 that overlaps the ledge 2010 exterior to the housing 2004. The retainer 2018 may be mechanically attached to the bracket 2016 by a set of screws 2020 or other mechanical fastener. The screws 2020 may be inserted into through-holes in the bracket 2016 and screwed into threaded holes in the retainer 2018, clamping the ledge 2010 between the bracket 2016 and the retainer 2018.

The conductive button cap 2012 may have an exterior surface 2022, a sidewall or set of sidewalls 2024 parallel to the sidewall 2008 of the cavity 2006, and an inward facing lip or set of lips 2026 that extends between the retainer 2018 and the ledge 2010 and toward a center axis of the conductive button cap 2012. A set of one or more coil springs 2028 or other spring-biased members may be positioned between an outer surface of the retainer 2018 and an underside of the conductive button cap 2012, and may bias the conductive button cap 2012 in an outward state of translation.

The button cap retention assembly 2014, and in particular the retainer 2018, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening 2002 in the housing 2004. A shaft 2030 may be positioned within the through-hole, and may translate toward and away from the housing 2004. The shaft 2030 may be mechanically and electrically connected to the conductive button cap 2012, or may be biased to contact the conductive button cap 2012. In a state of rest, the shaft 2030 and conductive button cap 2012 may be biased in an outward state of translation (i.e., away from the opening 2002) by the coil springs 2028 and/or a spring-biased tactile switch 2032. In some cases, a shim 2034, such as a non-conductive shim, may be attached to an end of the shaft 2030 facing the tactile

switch 2032. When a user presses the conductive button cap 2012 toward the housing 2004, the press may overcome the bias provided by the coil springs 2028 and/or tactile switch 2032, and pressure on the conductive button cap 2012 may be transferred to the shaft 2030, which translates toward the housing 2004 and presses on the tactile switch 2032 to change the state of the tactile switch 2032 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 2032 may be aligned with an axis of the shaft 2030 and attached to the bracket 2016 using an adhesive 2036 (e.g., a non-conductive PSA).

In some embodiments, a gasket 2038 (e.g., an O-ring) may be positioned between the shaft 2030 and the through-hole. In some cases, the gasket 2038 may be positioned between a first non-conductive liner 2044 and a second non-conductive liner 2046. In some examples, the gasket 2038 may be non-conductive.

The button assembly 2000 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap 2012 from the button cap retention assembly 2014 and housing 2004. For example, the button assembly 2000 may include a first electrical insulator, such as a sleeve 2042 (or set of shims), positioned between the conductive button cap 2012 and the sidewall 2008 (or set of sidewalls) of the cavity 2006 in the housing 2004. In some cases, the sleeve 2042 may include a closed-shape sidewall. In other cases, the sleeve 2042 may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner 2044 between an interior surface of the conductive button cap 2012 and the button cap retention assembly 2014. In some cases, the non-conductive liner 2044 may be press-fit or adhesively bonded to the interior surface of the conductive button cap 2012. Alternatively, the non-conductive liner 2044 may be press-fit or adhesively bonded to an exterior surface of the retainer 2018. In some embodiments, the non-conductive liner 2044 may extend into the through-hole, between the shaft 2030 and the button cap retention assembly 2014 (e.g., between the shaft 2030 and the retainer 2018). A third electrical insulator may include a second non-conductive liner 2046, positioned in the through-hole between the shaft 2030 and the retainer 2018, below the gasket 2038. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap 2012 from the button cap retention assembly 2014 (e.g., from the retainer 2018). The first electrical insulator may electrically insulate the conductive button cap 2012 from the housing 2004. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 2012 from the button cap retention assembly 2014 or housing 2004.

A conductive flexure 2048 may be coupled to, but insulated from, the bracket 2016, and positioned (e.g., angled) to contact the end of the shaft 2030 that faces the tactile switch 2032. The conductive flexure 2048 may be spring-biased to contact the end of the shaft 2030, and may be spring-biased to remain in contact with the end of the shaft 2030 during all states of translation of the shaft 2030.

In use, a signal may be applied to, or received from, the conductive button cap 2012 via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the conductive flexure 2048. A signal may travel through the conductive button cap 2012, shaft 2030, and conductive flexure 2048.

FIG. 21 shows an assembled cross-section of another example of a button assembly 2100 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. The button assembly 2100 may be at least partially within an opening 2102 in a housing 2104 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing 2104 may include a cavity 2106 defined by at least one sidewall (e.g., a single sidewall 2108 or set of sidewalls) and a ledge 2110. The ledge 2110 may define the opening 2102, and the sidewall 2108 may surround the ledge 2110.

The button assembly 2100 may include a conductive button cap 2112 (or button cap having a conduction portion). The conductive button cap 2112 may be retained by a button cap retention assembly 2114 (or button retainer), and may be translatable toward and away from the housing 2104. The button cap retention assembly 2114 may extend through the opening 2102 and be connected or otherwise attached to the housing 2104. In some examples, the button cap retention assembly 2114 may include a bracket 2116 that overlaps the ledge 2110 interior to the housing 2104, and a retainer 2118 that overlaps the ledge 2110 exterior to the housing 2104. The retainer 2118 may be mechanically attached to the bracket 2116 by a set of screws 2120 or other mechanical fastener. The screws 2120 may be inserted into through-holes in the bracket 2116 and screwed into threaded holes in the retainer 2118, clamping the ledge 2110 between the bracket 2116 and the retainer 2118.

The conductive button cap 2112 may have an exterior surface 2122, a sidewall or set of sidewalls 2124 parallel to the sidewall 2108 of the cavity 2106, and an inward facing lip or set of lips 2126 that extends between the retainer 2118 and the ledge 2110 and toward a center axis of the conductive button cap 2112.

The button cap retention assembly 2114, and in particular the retainer 2118, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening 2102 in the housing 2104. A shaft 2128 may be positioned within the through-hole, and may translate toward and away from the housing 2104. The shaft 2128 may be mechanically and electrically connected to the conductive button cap 2112, or may be biased to contact the conductive button cap 2112. In a state of rest, the shaft 2128 and conductive button cap 2112 may be biased in an outward state of translation (i.e., away from the opening 2102) by a conductive flexure 2130 or other spring-biased member positioned between the bracket 2116 and an end of the shaft 2128 that faces the bracket 2116.

The button cap retention assembly 2114, and in particular the retainer 2118, may also have a second through-hole formed therein, with an axis of the second through-hole extending perpendicular to the opening 2102 in the housing 2104. A piston 2132 may be positioned within the through-hole, and may translate toward and away from the housing 2104. In some cases, a shim 2134, such as a non-conductive shim, may be attached to an end of the piston 2132 facing a spring-biased tactile switch 2136. When a user presses the conductive button cap 2112 toward the housing 2104, the press may overcome the bias provided by the conductive flexure 2130 and/or tactile switch 2136, and pressure on the conductive button cap 2112 may be transferred to the piston 2132, which translates toward the housing 2104 and presses on the tactile switch 2136 to change the state of the tactile switch 2136 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 2136 may



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be aligned with an axis of the piston 2132 and attached to the bracket 2116 using an adhesive 2138 (e.g., a non-conductive PSA).

In some embodiments, a first gasket 2140 (e.g., an O-ring) may be positioned between the shaft 2128 and the first through-hole, and a second gasket 2142 (e.g., an O-ring) may be positioned between the piston 2132 and the second through-hole. In some cases, the first gasket 2140 may be positioned between a first non-conductive liner 2150 and a second non-conductive liner 2152. In some cases, the piston 2132 may have a circumferential groove 2146 in which a portion of the second gasket 2142 is seated so that the second gasket 2142 moves in a predictable way in response to movement of the piston 2132. In some examples, the first and second gaskets 2140, 2142 may be non-conductive.

The button assembly 2100 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap 2112 from the button cap retention assembly 2114 and housing 2104. For example, the button assembly 2100 may include a first electrical insulator, such as a sleeve 2148 (or set of shims), positioned between the conductive button cap 2112 and the sidewall 2108 (or set of sidewalls) of the cavity 2106 in the housing 2104. In some cases, the sleeve 2148 may include a closed-shape sidewall. In other cases, the sleeve 2148 may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner 2150 between an interior surface of the conductive button cap 2112 and the button cap retention assembly 2114. In some cases, the non-conductive liner 2150 may be press-fit or adhesively bonded to the interior surface of the conductive button cap 2112. Alternatively, the non-conductive liner 2150 may be press-fit or adhesively bonded to an exterior surface of the retainer 2118. In some embodiments, the non-conductive liner 2150 may extend into the through-hole, between the shaft 2128 and the button cap retention assembly 2114 (e.g., between the shaft 2128 and the retainer 2118). A third electrical insulator may include a second non-conductive liner 2152, positioned in the through-hole between the shaft 2128 and the retainer 2118, below the gasket 2140. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap 2112 from the button cap retention assembly 2114 (e.g., from the retainer 2118). The first electrical insulator may electrically insulate the conductive button cap 2112 from the housing 2104. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 2112 from the button cap retention assembly 2114 or housing 2104.

In use, a signal may be applied to, or received from, the conductive button cap 2112 via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the conductive flexure 2130. A signal may travel through the conductive button cap 2112, shaft 2128, and conductive flexure 2130.

FIG. 22 shows an assembled cross-section of another example of a button assembly 2200 that may be included in any of the electronic devices described with reference to FIG. 1A, 1B, 2A-2C, 3, 4A, or 4B. The button assembly 2200 may be at least partially within an opening 2202 in a housing 2204 (e.g., an opening in the housing described with reference to FIG. 2A, 2C, 3, 4A, or 4B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing 2204 may include a cavity 2206 defined by at least one sidewall (e.g., a single

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sidewall 2208 or set of sidewalls) and a ledge 2210. The ledge 2210 may define the opening 2202, and the sidewall 2208 may surround the ledge 2210.

The button assembly 2200 may include a conductive button cap 2212 (or button cap having a conductive portion). The conductive button cap 2212 may be retained by a button cap retention assembly 2214 (or button retainer), and may be translatable toward and away from the housing 2204. The button cap retention assembly 2214 may extend through the opening 2202 and be connected or otherwise attached to the housing 2204. In some examples, the button cap retention assembly 2214 may include a bracket 2216 that overlaps the ledge 2210 interior to the housing 2204, and a retainer 2218 that overlaps the ledge 2210 exterior to the housing 2204. The retainer 2218 may be mechanically attached to the bracket 2216 by a set of screws 2220 or other mechanical fastener. The screws 2220 may be inserted into through-holes in the bracket 2216 and screwed into threaded holes in the retainer 2218, clamping the ledge 2210 between the bracket 2216 and the retainer 2218.

The conductive button cap 2212 may have an exterior surface 2222, a sidewall or set of sidewalls 2224 parallel to the sidewall 2208 of the cavity 2206, and an inward facing lip or set of lips 2226 that extends between the retainer 2218 and the ledge 2210 and toward a center axis of the conductive button cap 2212.

The button cap retention assembly 2214, and in particular the retainer 2218, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening 2202 in the housing 2204. A shaft 2228 may be positioned within the through-hole, and may translate toward and away from the housing 2204. The shaft 2228 may be mechanically and electrically connected to the conductive button cap 2212, or may be biased to contact the conductive button cap 2212. In a state of rest, the shaft 2228 and conductive button cap 2212 may be biased in an outward state of translation (i.e., away from the opening 2202) by a conductive spring (e.g., a coil spring 2230) or other spring-biased member positioned between the bracket 2216 and an end of the shaft 2228 that faces the bracket 2216.

The button cap retention assembly 2214, and in particular the retainer 2218, may also have a second through-hole formed therein, with an axis of the second through-hole extending perpendicular to the opening 2202 in the housing 2204. A piston 2232 may be positioned within the through-hole, and may translate toward and away from the housing 2204. When a user presses the conductive button cap 2212 toward the housing 2204, the press may overcome the bias provided by the coil spring 2230 and/or tactile switch 2234, and pressure on the conductive button cap 2212 may be transferred to the piston 2232, which translates toward the housing 2204 and presses on the tactile switch 2234 to change the state of the tactile switch 2234 (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch 2234 may be aligned with an axis of the piston 2232 and attached to the bracket 2216 using an adhesive 2236 (e.g., a non-conductive PSA).

In some embodiments, a first gasket 2238 (e.g., an O-ring) may be positioned between the shaft 2228 and the first through-hole, and a second gasket 2240 (e.g., an O-ring) may be positioned between the piston 2232 and the second through-hole. In some cases, the first gasket 2238 may be positioned between a first non-conductive liner 2248 and a second non-conductive liner 2250. In some cases, the piston 2232 may have a circumferential groove 2244 in which a portion of the second gasket 2240 is seated so that the second gasket 2240 moves in a predictable way in response

to movement of the piston 2232. In some examples, the first and second gaskets 2238, 2240 may be non-conductive.

The button assembly 2200 may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap 2212 from the button cap retention assembly 2214 and housing 2204. For example, the button assembly 2200 may include a first electrical insulator, such as a sleeve 2246 (or set of shims), positioned between the conductive button cap 2212 and the sidewall 2208 (or set of sidewalls) of the cavity 2206 in the housing 2204. In some cases, the sleeve 2246 may include a closed-shape sidewall. In other cases, the sleeve 2246 may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner 2248 between an interior surface of the conductive button cap 2212 and the button cap retention assembly 2214. In some cases, the non-conductive liner 2248 may be press-fit or adhesively bonded to the interior surface of the conductive button cap 2212. Alternatively, the non-conductive liner 2248 may be press-fit or adhesively bonded to an exterior surface of the retainer 2218. In some embodiments, the non-conductive liner 2248 may extend into the through-hole, between the shaft 2228 and the button cap retention assembly 2214 (e.g., between the shaft 2228 and the retainer 2218). A third electrical insulator may include a second non-conductive liner 2250, positioned in the through-hole between the shaft 2228 and the retainer 2218, below the gasket 2238. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap 2212 from the button cap retention assembly 2214 (e.g., from the retainer 2218). The first electrical insulator may electrically insulate the conductive button cap 2212 from the housing 2204. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap 2212 from the button cap retention assembly 2214 or housing 2204.

In use, a signal may be applied to, or received from, the conductive button cap 2212 via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the coil spring 2230. A signal may travel through the conductive button cap 2212, shaft 2228, and coil spring 2230.

FIG. 23 shows a schematic 2300 of an electronic device, such as an electronic watch, that may be used for acquiring an ECG or other biological parameter from a user of the electronic device. In some cases, the electronic device may include a watch body. As shown, the electronic device may include a first electrode 2302 on a carrier 2304, an optional second electrode 2306 on the carrier 2304, and a third electrode 2308 on the surface of a user-rotatable crown 2310 (or alternatively, on the surface of a button). The third electrode 2308 may be operable to be contacted by a finger of a user while the first electrode 2302 (and optional second electrode 2306) are positioned against a user's skin (e.g., against the wrist of the user). A processor 2312, which in some cases may be provided in an integrated circuit (IC), an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), a system in package (SIP), a system on a chip (SOC), etc., may be operable to acquire an ECG from the user, or determine another biological parameter of, the user. The ECG or other biological parameter may be determined based on voltages at the first, optional second, and third electrodes 2302, 2306, 2308 while the user is in contact with the first, optional second, and third electrodes 2302, 2306, 2308.

In some cases, voltages may be sensed at just the first and third electrodes 2302, 2308. In other cases, the second electrode 2306 may be grounded to the electronic device, thereby the user to the electronic device, and the voltage at the second electrode 2306 (i.e., the ground voltage) may be used to remove noise generated by the electronic device or other environmental sources from the signals measured at the first and third electrodes 2302, 2308. This may result in more accurate readings (or processing) of the first and third voltages.

As shown, a signal or voltages at the first electrode 2302 may be amplified by a first amplifier 2314, and a signal or voltages at the third electrode 2308 may be amplified by a second amplifier 2316.

FIG. 24 shows an example method 2400 of determining a biological parameter of a user wearing an electronic watch or other wearable electronic device, such as a watch or wearable electronic device described herein.

At block 2402, a ground voltage is optionally applied to a user via a first electrode on the electronic device. The first electrode may be on an exterior surface of a carrier that forms part of a housing of the electronic device. The operation(s) at 2402 may be performed, for example, by the processor described with reference to FIG. 24, using one of the electrodes described with reference to FIGS. 1B, 2A-2C, 3, 4A-4C, 5D, 5E, 6-8, 9A-9C, 10A-10D, & 23.

At block 2404, a first voltage or signal is sensed at a second electrode on the electronic device. The second electrode may also be on the exterior surface of the carrier. The operation(s) at 2404 may be performed, for example, by the processor described with reference to FIG. 24, using one of the electrodes described with reference to FIGS. 1B, 2A-2C, 3, 4A-4C, 5D, 5E, 6-8, 9A-9C, 10A-10D, 11, 12A, 12B, 13, 14, 15, 16A, 16B, 17A, 17B, 18A, 18B, 19, 20, 21, 22, & 23.

At block 2406, a second voltage or signal is sensed at a third electrode on the electronic device. The third electrode may be on a user-rotatable crown of the electronic device, or on a button of the electronic device, or on another surface of the housing of the electronic device. In some embodiments, the ground voltage is applied and the first voltage or signal is sensed on a wrist of one arm of the user, and the second voltage or signal is sensed on a fingertip of the user (with the fingertip belonging to a finger on a hand on the other arm of the user). The operation(s) at 2406 may be performed, for example, by the processor described with reference to FIG. 24, using one of the electrodes described with reference to FIGS. 1B, 2A-2C, 3, 4A-4C, 5D, 5E, 6-8, 9A-9C, 10A-10D, 11, 12A, 12B, 13, 14, 15, 16A, 16B, 17A, 17B, 18A, 18B, 19, 20, 21, 22, & 23.

At block 2408, the biological parameter of the user may be determined from the optional ground voltage, the first voltage or signal, and the second voltage or signal. The ground voltage may provide a reference for the first and second voltages or signals, or may otherwise be used to reject noise from the first and second voltages or signals. When the first and second voltages are obtained from different parts of the user's body, the biological parameter may be an electrocardiogram for the user. The operation(s) at 2408 may be performed, for example, by the processor described with reference to FIG. 25.

FIG. 25 shows a sample electrical block diagram of an electronic device 2500, which electronic device may in some cases take the form of any of the electronic watches or other wearable electronic devices described with reference to FIGS. 1-23, or other portable or wearable electronic devices. The electronic device 2500 can include a display 2505 (e.g., a light-emitting display), a processor 2510, a



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power source 2515, a memory 2520 or storage device, a sensor 2525, and an input/output (I/O) mechanism 2530 (e.g., an input/output device, input/output port, or haptic input/output interface). The processor 2510 can control some or all of the operations of the electronic device 2500. The processor 2510 can communicate, either directly or indirectly, with some or all of the components of the electronic device 2500. For example, a system bus or other communication mechanism 2535 can provide communication between the processor 2510, the power source 2515, the memory 2520, the sensor 2525, and the input/output mechanism 2530.

The processor 2510 can be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processor 2510 can be a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

It should be noted that the components of the electronic device 2500 can be controlled by multiple processors. For example, select components of the electronic device 2500 (e.g., a sensor 2525) may be controlled by a first processor and other components of the electronic device 2500 (e.g., the display 2505) may be controlled by a second processor, where the first and second processors may or may not be in communication with each other. In some cases, the processor 2510 may determine a biological parameter of a user of the electronic device, such as an ECG for the user.

The power source 2515 can be implemented with any device capable of providing energy to the electronic device 2500. For example, the power source 2515 may be one or more batteries or rechargeable batteries. Additionally or alternatively, the power source 2515 can be a power connector or power cord that connects the electronic device 2500 to another power source, such as a wall outlet.

The memory 2520 can store electronic data that can be used by the electronic device 2500. For example, the memory 2520 can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing signals, control signals, and data structures or databases. The memory 2520 can be configured as any type of memory. By way of example only, the memory 2520 can be implemented as random access memory, read-only memory, Flash memory, removable memory, other types of storage elements, or combinations of such devices.

The electronic device 2500 may also include one or more sensors 2525 positioned almost anywhere on the electronic device 2500. The sensor(s) 2525 can be configured to sense one or more type of parameters, such as but not limited to, pressure, light, touch, heat, movement, relative motion, biometric data (e.g., biological parameters), and so on. For example, the sensor(s) 2525 may include a heat sensor, a position sensor, a light or optical sensor, an accelerometer, a pressure transducer, a gyroscope, a magnetometer, a health monitoring sensor, and so on. Additionally, the one or more sensors 2525 can utilize any suitable sensing technology, including, but not limited to, capacitive, ultrasonic, resistive, optical, ultrasound, piezoelectric, and thermal sensing technology. In some examples, the sensors 2525 may include one or more of the electrodes described herein (e.g., one or more electrodes on an exterior surface of a carrier that forms

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part of a housing for the electronic device 2500 and/or an electrode on a crown, button, or other housing member of the electronic device).

The I/O mechanism 2530 can transmit and/or receive data from a user or another electronic device. An I/O device can include a display, a touch sensing input surface, one or more buttons (e.g., a graphical user interface "home" button), one or more cameras, one or more microphones or speakers, one or more ports such as a microphone port, and/or a keyboard. Additionally or alternatively, an I/O device or port can transmit electronic signals via a communications network, such as a wireless and/or wired network connection. Examples of wireless and wired network connections include, but are not limited to, cellular, Wi-Fi, Bluetooth, IR, and Ethernet connections.

As discussed above, graphics displayed on the electronic devices herein may be manipulated through inputs provided to the crown. FIGS. 26A-28B generally depict examples of changing a graphical output displayed on an electronic device through inputs provided by force and/or rotational inputs to a crown assembly of the device. This manipulation (e.g., selection, acknowledgement, motion, dismissal, magnification, and so on) of a graphic may result in changes in operation of the electronic device and/or graphical output displayed by the electronic device. Although specific examples are provided and discussed, many operations may be performed by rotating and/or applying force to a crown such as the examples described above. Accordingly, the following discussion is by way of example and not limitation.

FIG. 26A depicts an example electronic device 2600 (shown here as an electronic watch) having a crown 2602. The crown 2602 may be similar to the examples described above, and may receive force inputs along a first lateral direction, a second lateral direction, or an axial direction of the crown. The crown 2602 may also receive rotational inputs. A display 2606 provides a graphical output (e.g., shows information and/or other graphics). In some embodiments, the display 2606 may be configured as a touch-sensitive display capable of receiving touch and/or force input. In the current example, the display 2606 depicts a list of various items 2661, 2662, 2663, all of which are example graphics.

FIG. 26B illustrates how the graphical output shown on the display 2606 changes in a first manner as the crown 2602 rotates, partially or completely (as indicated by the arrow 2660). Rotating the crown 2602 causes the list to scroll or otherwise move on the screen, such that the first item 2661 is no longer displayed, the second and third items 2662, 2663 each move upwards on the display, and a fourth item 2664 is now shown at the bottom of the display. This is one example of a scrolling operation that can be executed by rotating the crown 2602. Such scrolling operations may provide a simple and efficient way to depict multiple items relatively quickly and in sequential order. A speed of the scrolling operation may be controlled by the amount of rotational force applied to the crown 2602 and/or the speed at which the crown 2602 is rotated. Faster or more forceful rotation may yield faster scrolling, while slower or less forceful rotation yields slower scrolling. The crown 2602 may receive an axial force (e.g., a force inward toward the display 2606 or watch body) to select an item from the list, in certain embodiments.

FIGS. 27A and 27B illustrate an example zoom operation. The display 2706 depicts a picture 2766 at a first magnification, shown in FIG. 27A; the picture 2766 is yet another example of a graphic. A user may apply a translating force



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(e.g., a force along the z-axis) or a lateral force (e.g., a force along the x-axis) to the crown 2702 of the electronic device 2700 (illustrated by arrow 2765), and in response the display may change a graphic in a second manner, such as zooming into the picture 2766 so that a portion 2767 of the picture is shown at an increased magnification. This is shown in FIG. 27B. The direction of zoom (in vs. out) and speed of zoom, or location of zoom, may be controlled through force applied to the crown 2702, and particularly through the direction of applied force and/or magnitude of applied force. Applying force to the crown 2702 in a first direction may zoom in, while applying force to the crown 2702 in an opposite direction may zoom out. Alternately, rotating or applying force to the crown 2702 in a first direction may change the portion of the picture subject to the zoom effect. In some embodiments, applying an axial or translating force (e.g., a force along the z-axis) to the crown 2702 may toggle between different zoom modes or inputs (e.g., direction of zoom vs. portion of picture subject to zoom), or otherwise change the displayed graphic in a second manner. In yet other embodiments, applying force to the crown 2702 along another direction, such as along the y-axis, may return the picture 2766 to the default magnification shown in FIG. 27A.

FIGS. 28A and 28B illustrate possible use of the crown 2802 to change an operational state of the electronic device 2800 or otherwise toggle between inputs. Turning first to FIG. 28A, the display 2806 depicts a question 2868, namely, "Would you like directions?" As shown in FIG. 28B, a lateral force may be applied to the crown 2802 (illustrated by arrow 2870) to answer the question. Applying force to the crown 2802 provides an input interpreted by the electronic device 2800 as "yes," and so "YES" is displayed as a graphic 2869 on the display 2806. Applying force to the crown 2802 in an opposite direction may provide a "no" input. Both the question 2868 and graphic 2869 are examples of graphics.

In the embodiment shown in FIGS. 28A and 28B, the force applied to the crown 2802 is used to directly provide the input, rather than select from options in a list (as discussed above with respect to FIGS. 26A and 26B).

As mentioned previously, force or rotational input to a crown of an electronic device may control many functions beyond those listed here. The crown may receive distinct force or rotational inputs to adjust a volume of an electronic device, a brightness of a display, or other operational parameters of the device. A force or rotational input applied to the crown may rotate to turn a display on or off, or turn the device on or off. A force or rotational input to the crown may launch or terminate an application on the electronic device. Further, combinations of inputs to the crown may likewise initiate or control any of the foregoing functions, as well.

In some cases, the graphical output of a display may be responsive to inputs applied to a touch-sensitive display (e.g., displays 2606, 2706, 2806, and the like) in addition to inputs applied to a crown. The touch-sensitive display may include or be associated with one or more touch and/or force sensors that extend along an output region of a display and which may use any suitable sensing elements and/or sensing techniques to detect touch and/or force inputs applied to the touch-sensitive display. The same or similar graphical output manipulations that are produced in response to inputs applied to the crown may also be produced in response to inputs applied to the touch-sensitive display. For example, a swipe gesture applied to the touch-sensitive display may cause the graphical output to move in a direction corresponding to the swipe gesture. As another example, a tap gesture applied to the touch-sensitive display may cause an

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item to be selected or activated. In this way, a user may have multiple different ways to interact with and control an electronic watch, and in particular the graphical output of an electronic watch. Further, while the crown may provide overlapping functionality with the touch-sensitive display, using the crown allows for the graphical output of the display to be visible (without being blocked by the finger that is providing the touch input).

As another example, and of the inputs described in FIGS. 26A-28B may be used to select, initiate, or display an ECG, or otherwise begin the operation of determining an ECG or launching an ECG application.

As described above, one aspect of the present technology is the gathering and use of data available from various sources, including the gathering and use of biological parameters of a user, to monitor or improve the user's health or fitness. The present disclosure contemplates that in some instances, this gathered data may include personal information data that uniquely identifies a specific person, or can be used to contact, locate, or identify a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, twitter IDs, home addresses, data or records relating to a user's health or level of fitness (e.g., vital sign measurements, medication information, exercise information), date of birth, or any other identifying or personal information.

The present disclosure recognizes that the use of such personal information data, in the present technology, can be used to the benefit of users. For example, the personal information data can be used to aid a user in monitoring or improving their health or fitness (e.g., biological parameters or health and fitness data may be used to provide insights into a user's general wellness, or may be used as positive feedback to individuals using technology to pursue wellness goals).

The present disclosure contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. Such policies should be easily accessible by users, and should be updated as the collection and/or use of data changes. Personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection/sharing should occur after receiving the informed consent of the users. Additionally, such entities should consider taking any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices. In addition, policies and practices should be adapted for the particular types of personal information data being collected and/or accessed and adapted to applicable laws and standards, including jurisdiction-specific considerations. For instance, in the US, collection of or access to certain health data may be governed by federal and/or state laws, such as the Health Insurance Portability and Accountability Act (HIPAA); whereas health data in other countries may be subject to other regulations and policies and should

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be handled accordingly. Hence different privacy practices should be maintained for different personal data types in each country.

Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, in the case of biological parameters or conditions identified therefrom, the present technology can be configured to allow users to select to “opt in” or “opt out” of participation in the collection of personal information data during registration for services or anytime thereafter. In another example, users can select not to provide health or fitness-associated data to the providers of applications or services, or can prevent the transmission of such data from the device on which it is collected or outside a collection of devices that are personal to a user from which the data is obtained. In yet another example, a user can select to limit the length of time health or fitness data, or biological parameters from which such data is derived, is maintained. In addition to providing “opt in” and “opt out” options, the present disclosure contemplates providing notifications relating to the access or use of personal information. For instance, a user may be notified upon downloading an app that their personal information data will be accessed and then reminded again just before personal information data is accessed by the app.

Moreover, it is the intent of the present disclosure that personal information data should be managed and handled in a way to minimize risks of unintentional or unauthorized access or use. Risk can be minimized by limiting the collection of data and deleting data once it is no longer needed. In addition, and when applicable, including in certain health related applications, data de-identification can be used to protect a user’s privacy. De-identification may be facilitated, when appropriate, by removing specific identifiers (e.g., date of birth, etc.), controlling the amount or specificity of data stored (e.g., collecting location data at a city level rather than at an address level), controlling how data is stored (e.g., aggregating data across users), and/or other methods.

Therefore, although the present disclosure broadly covers use of personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing at least some personal information data. That is, the various embodiments of the present technology are not rendered inoperable due to the lack of a portion of such personal information data. For example, biological parameters can be ascertained or stored without associating the biological parameters with information identifying a particular user from which they are obtained, or with a bare minimum amount of personal information, such as non-personal information already available to service providers or publicly available information.

The foregoing description, for purposes of explanation, uses specific nomenclature to provide a thorough understanding of the described embodiments. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the described embodiments. Thus, the foregoing descriptions of the specific embodiments described herein are presented for purposes of illustration and description. They are not targeted to be exhaustive or to limit the embodiments to the precise forms

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disclosed. It will be apparent to one of ordinary skill in the art that many modifications and variations are possible in view of the above teachings.

What is claimed is:

1. An electronic watch comprising:

a housing member;

a display at least partially enclosed by the housing member;

a carrier assembly coupled to the housing member and comprising:

a carrier member formed from a transparent material;

a first electrode positioned on the carrier member, operably coupled to a processor and configured to detect a first voltage; and

a second electrode positioned on the carrier member, operably coupled to the processor and configured to detect a second voltage, the first and second electrodes at least partially surrounding a first region of the carrier member and a second region of the carrier member;

a light emitter positioned below the first region of the carrier member;

a light receiver positioned below the second region of the carrier member and configured to receive light reflected from a wrist;

a third electrode coupled to the housing member, operably coupled to the processor, and configured to detect a third voltage; and

the processor positioned within the electronic watch and configured to determine an electrocardiogram using the first voltage, the second voltage, and the third voltage.

2. The electronic watch of claim 1, wherein:

the light receiver is a first light receiver;

the electronic watch further comprises a second light receiver; and

the first and second light receivers are configured to measure a heart rate using the light reflected from the wrist.

3. The electronic watch of claim 1, wherein:

the housing member defines a rectangular outer housing profile;

the display is a rectangular display; and

the carrier member defines a circular outer carrier profile.

4. The electronic watch of claim 1, wherein:

the first electrode includes a first conductive coating deposited on the carrier member; and

the second electrode includes a second conductive coating deposited on the carrier member.

5. The electronic watch of claim 4, wherein the first and second conductive coatings include one or more of an aluminum titanium nitride material, a chromium silicon carbon nitride material, or a diamond like carbon material.

6. The electronic watch of claim 4, wherein:

the first conductive coating is deposited along an exterior surface of the carrier member, an edge of the carrier member, and an interior surface of the carrier member; and

the processor is operably coupled to the first electrode along a portion of the first conductive coating positioned along the interior surface of the carrier member.

7. The electronic watch of claim 1, wherein:

the electronic watch further comprises a button having a conductive button cap; and

the conductive button cap defines the third electrode.

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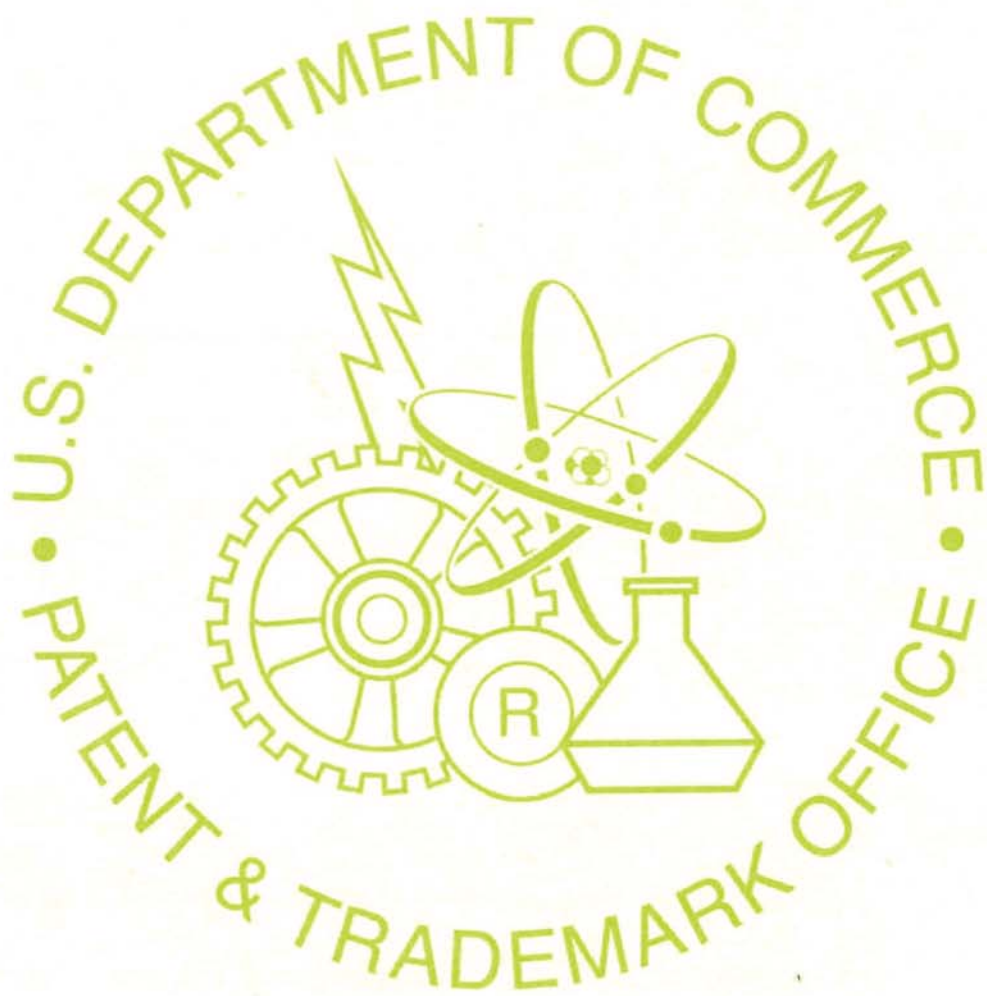
8. The electronic watch of claim 1, wherein:  
the carrier member includes an opaque ink mask depos-  
ited along an inner surface of the carrier member  
surrounding the first and second regions;  
the first and second electrodes are positioned along an  
exterior surface of the carrier member that is over the  
opaque ink mask; and  
the exterior surface of the carrier member protrudes  
outward from an external surface of the housing mem-  
ber.  
9. A wearable electronic device comprising:  
a rectangular housing member defining a rectangular front  
opening and a circular rear opening;  
a cover having a rectangular cover profile and positioned  
over the rectangular front opening;  
a display positioned below the cover;  
a carrier assembly coupled to the rectangular housing  
member and comprising:  
a carrier member having a circular carrier profile and  
positioned over the circular rear opening;  
a rear electrode positioned on the carrier member and  
configured to receive a first voltage signal from a  
wrist of a user;  
an optical sensor system comprising:  
an optical emitter positioned below a first region of the  
carrier member; and  
an optical receiver positioned below a second region of  
the carrier member;  
a side electrode positioned along an exterior of the  
rectangular housing member and configured to receive  
a second voltage signal from a finger of the user; and  
a processor positioned within the wearable electronic  
device and configured to determine a biological param-  
eter using the first and second voltage signals.  
10. The wearable electronic device of claim 9, wherein:  
the rear electrode is a first rear electrode; and  
the wearable electronic device further comprises a second  
rear electrode positioned on the carrier member and  
configured to ground the wearable electronic device to  
the user.  
11. The wearable electronic device of claim 10, wherein:  
the first rear electrode defines a first arc that partially  
surrounds the optical sensor system; and  
the second rear electrode defines a second arc that par-  
tially surrounds the optical sensor system.  
12. The wearable electronic device of claim 9, wherein:  
the rear electrode is formed from a conductive coating  
deposited along an exterior surface of the carrier mem-  
ber; and  
the conductive coating extends around an edge of the  
carrier member and along an inner portion of the carrier  
member that is internal to the wearable electronic  
device.  
13. The wearable electronic device of claim 9, wherein the  
optical sensor system is an optical heart rate sensor that is  
configured to measure a heart rate of the user.

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14. The wearable electronic device of claim 9, wherein:  
the optical sensor system is configured to measure a heart  
rate of the user; and  
the biological parameter is an electrocardiogram (ECG) of  
the user.  
15. A watch comprising:  
a housing member;  
a display configured to display a graphical output;  
a carrier assembly coupled to the housing member and  
comprising:  
a carrier member protruding outward from an external  
surface of the housing member; and  
a rear electrode positioned on the carrier member, the  
rear electrode operably coupled to a processor and  
configured to detect a first voltage;  
an optical sensor positioned below the carrier member and  
configured to transmit optical signals through the car-  
rier member;  
a side electrode positioned along an exterior of the watch,  
the side electrode operably coupled to the processor  
and configured to detect a second voltage; and  
the processor positioned within the watch and configured  
to:  
determine a biological parameter; and  
cause a change to the graphical output in response to  
determining the biological parameter.  
16. The watch of claim 15, wherein:  
the carrier member defines a circular outer profile;  
the optical sensor comprises a light emitter configured to  
emit light through a first region of the carrier member;  
the optical sensor comprises an optical receiver config-  
ured to receive reflected light through a second region  
of the carrier member; and  
the rear electrode is positioned along a peripheral region  
of the carrier member and at least partially surrounds  
the first and second regions of the carrier member.  
17. The watch of claim 15, wherein:  
the rear electrode is a first rear electrode;  
the watch further comprises a second rear electrode  
positioned on the carrier member; and  
the first rear electrode and the second rear electrode are  
defined by a conductive coating deposited on a surface  
of the carrier member.  
18. The watch of claim 17, wherein the second rear  
electrode is configured to ground the watch to a portion of  
a skin of a user wearing the watch.  
19. The watch of claim 15, wherein:  
the rear electrode includes a conductive coating that  
includes one or more of an aluminum titanium nitride  
or a chromium silicon carbon nitride material; and  
the conductive coating extends along an edge of the  
carrier member and along an interior surface of the  
carrier member.  
20. The watch of claim 15, wherein:  
the watch further comprises a button; and  
the side electrode is positioned along a surface of the  
button.

\* \* \* \* \*

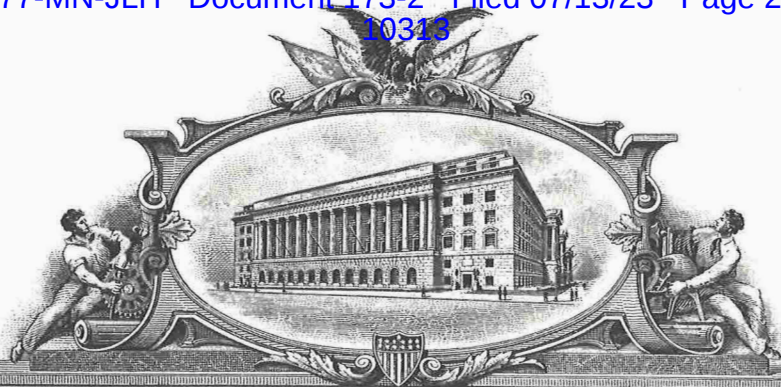




# EXHIBIT 9



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# THE UNITED STATES OF AMERICA

**TO ALL TO WHOM THESE PRESENTS SHALL COME:**

UNITED STATES DEPARTMENT OF COMMERCE  
United States Patent and Trademark Office


February 2, 2023

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM  
THE RECORDS OF THIS OFFICE OF:

PATENT NUMBER: *11,106,352*

ISSUE DATE: *August 31, 2021*

By Authority of the  
Under Secretary of Commerce for Intellectual Property  
and Director of the United States Patent and Trademark Office

  
Curtis Goffe  
Certifying Officer





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(12) **United States Patent**  
**Tyler**

(10) **Patent No.: US 11,106,352 B2**  
(45) **Date of Patent: Aug. 31, 2021**

(54) **DEVICES, METHODS, AND GRAPHICAL USER INTERFACES FOR ACCESSING NOTIFICATIONS**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.**  
**G06F 3/0488** (2013.01)  
**G06F 1/3234** (2019.01)  
(Continued)

(52) **U.S. Cl.**  
CPC ..... **G06F 3/0488** (2013.01); **G06F 1/1694** (2013.01); **G06F 1/3262** (2013.01);  
(Continued)

(58) **Field of Classification Search**

None  
See application file for complete search history.

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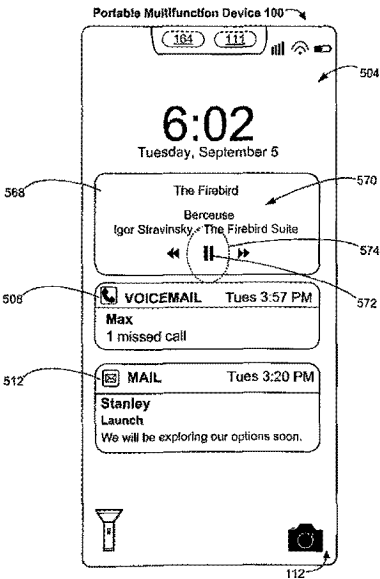
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(57) **ABSTRACT**

While displaying the wake screen user interface, in response to detecting a first input that is directed to a portion of the wake screen user interface: if the first input includes first movement in a first direction, the computer system displays of a home screen user interface; and the first movement is in a second direction, the computer system displays a widget screen user interface that is different from the wake screen user interface and the home screen user interface, wherein the widget screen user interface includes a plurality of user interface objects corresponding to different applications, wherein a respective user interface object of the plurality of user interface objects contains application content from an application corresponding to the respective user interface object, and when selected, causes display of an application corresponding to the respective user interface object.

**24 Claims, 253 Drawing Sheets**



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*H04L 12/58* (2006.01)  
*G06F 21/36* (2013.01)  
*G06F 3/0481* (2013.01)  
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*G06F 21/62* (2013.01)  
*H04M 1/724* (2021.01)  
*H04M 1/72436* (2021.01)

(52) U.S. Cl.

CPC ..... *G06F 1/3265* (2013.01); *G06F 3/016* (2013.01); *G06F 3/0485* (2013.01); *G06F 3/04817* (2013.01); *G06F 3/04883* (2013.01); *G06F 21/36* (2013.01); *G06F 21/629* (2013.01); *H04L 51/24* (2013.01); *H04M 1/673* (2013.01); *H04M 1/724* (2021.01); *H04L 51/32* (2013.01); *H04M 1/72436* (2021.01); *H04M 2250/22* (2013.01)

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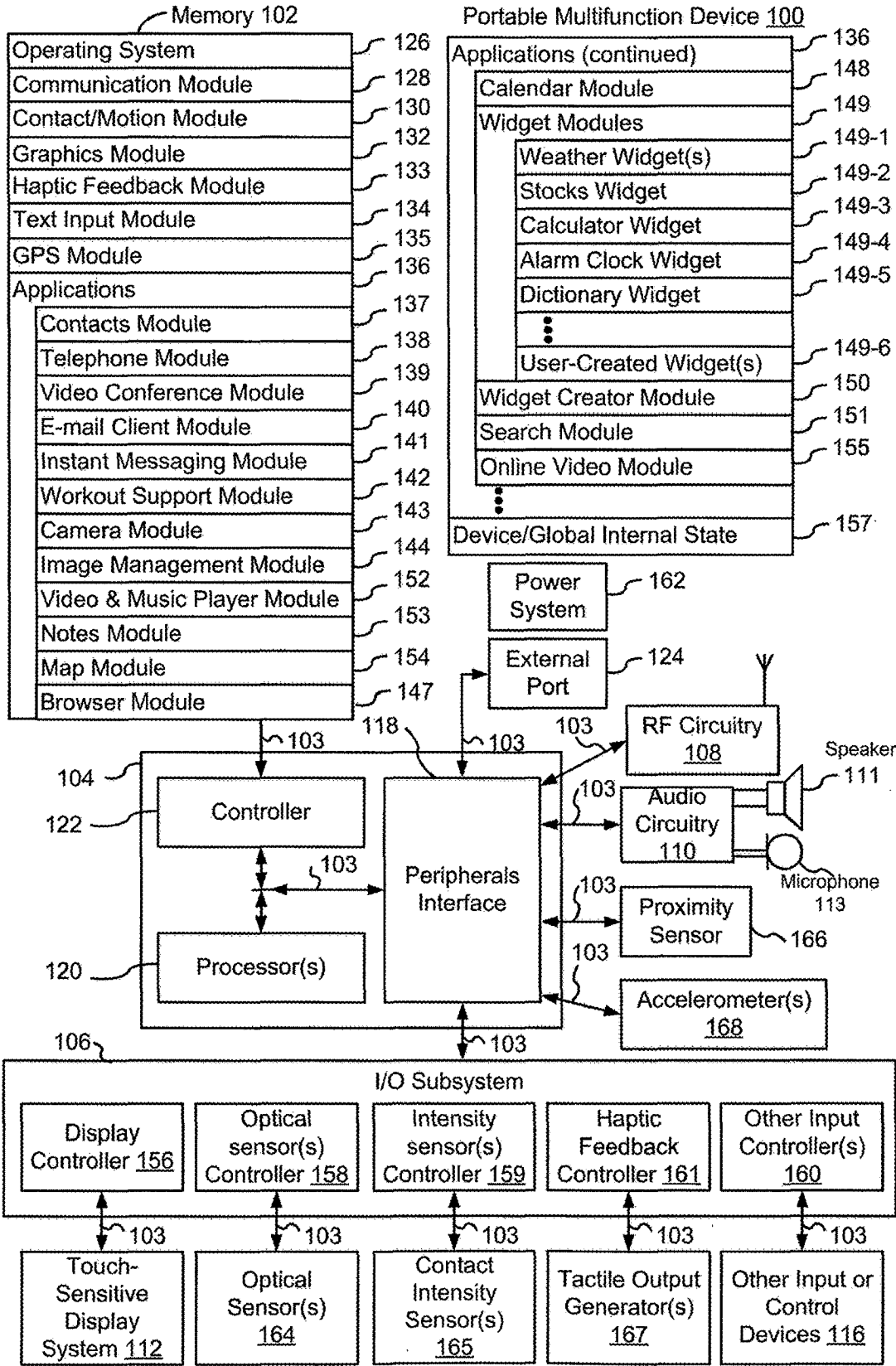


Figure 1A



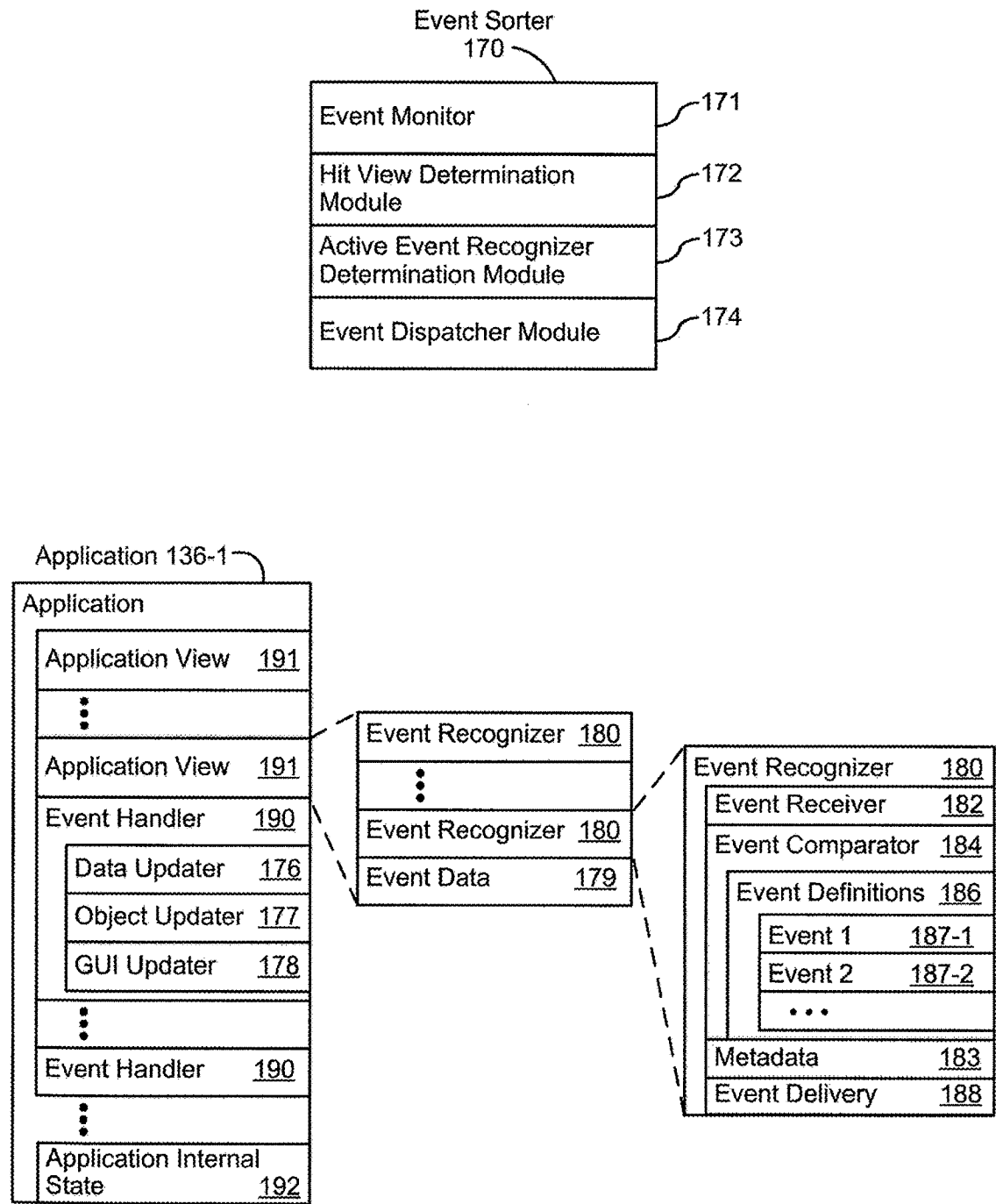


Figure 1B



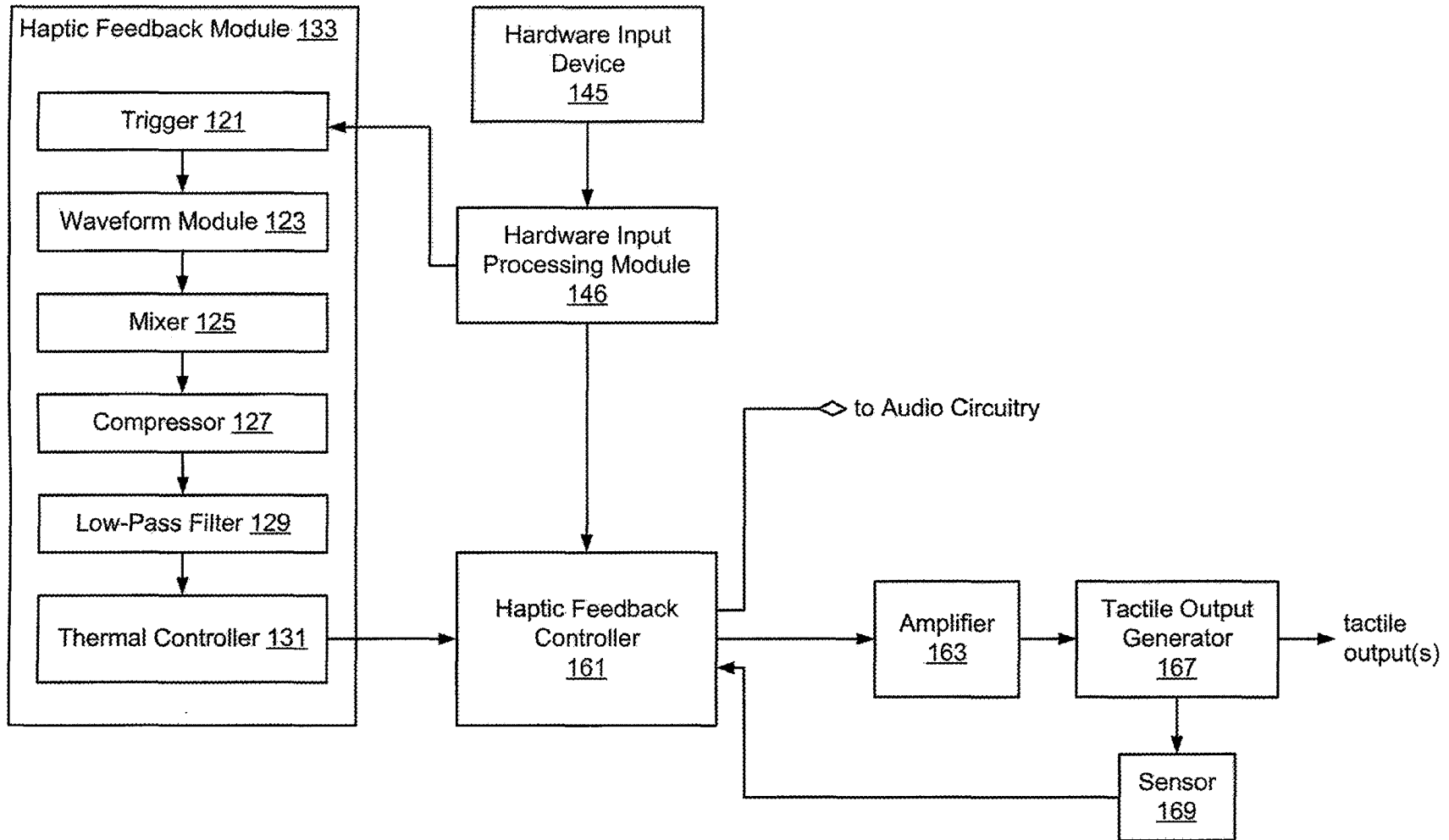


Figure 1C

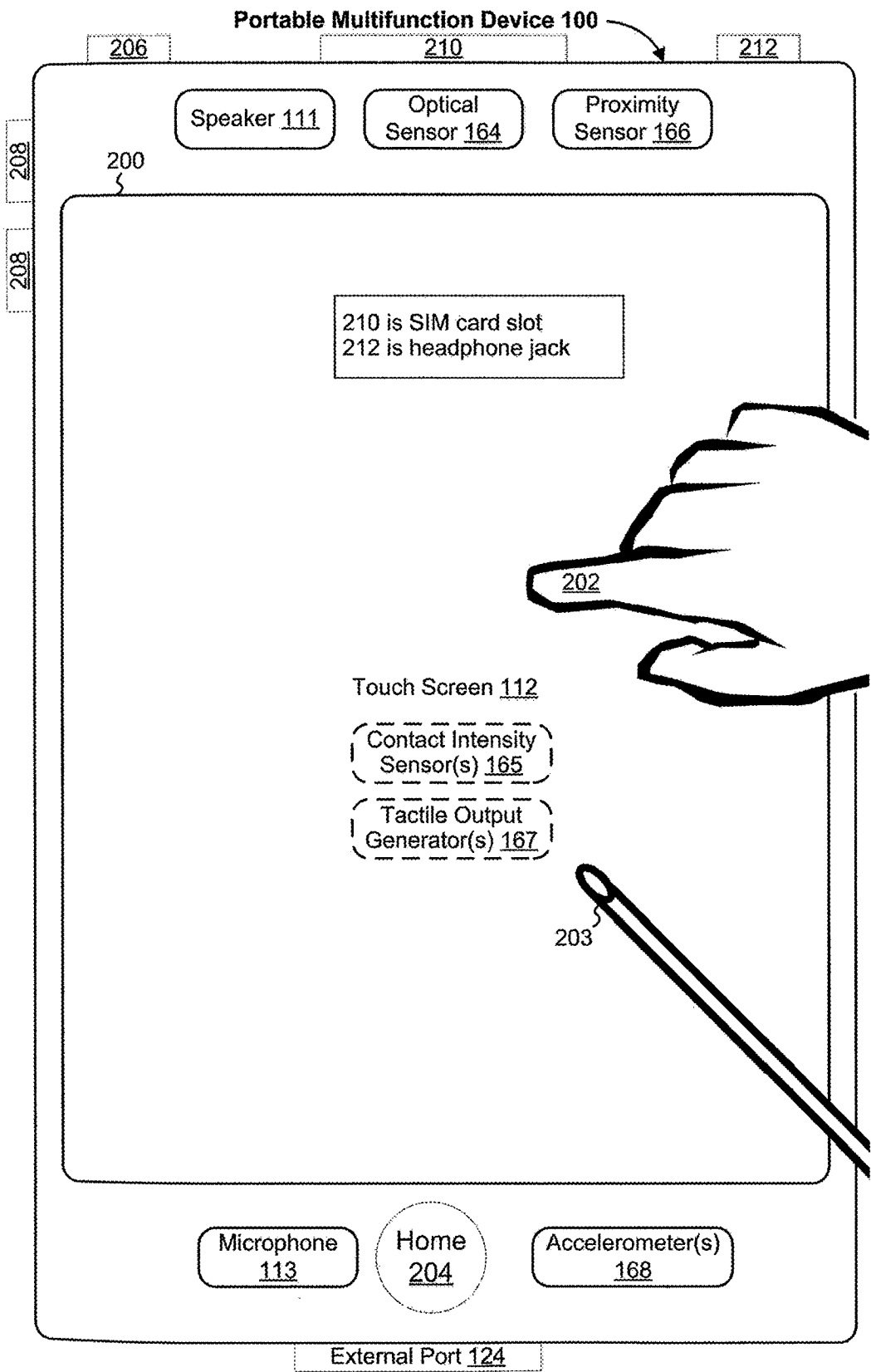


Figure 2

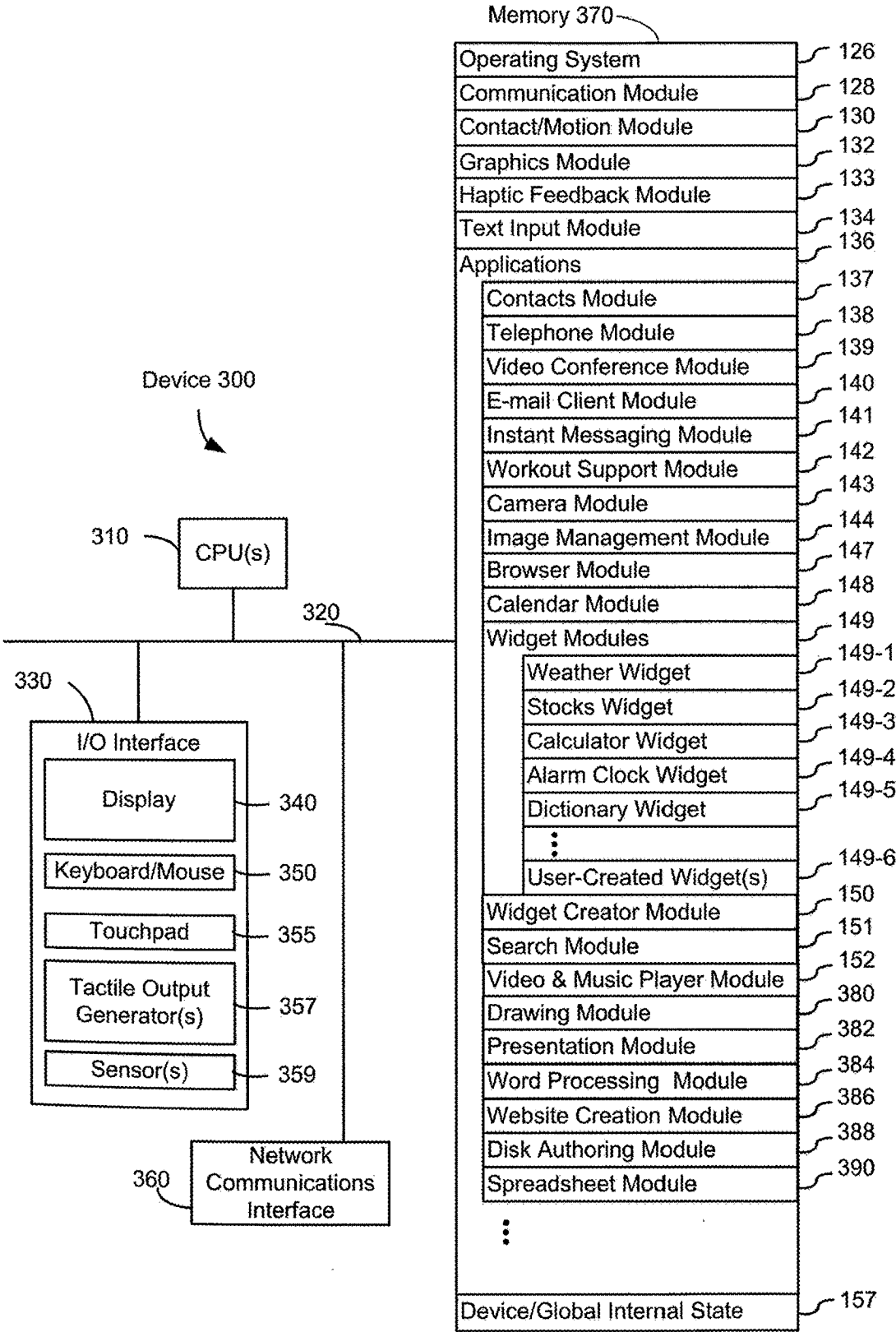


Figure 3

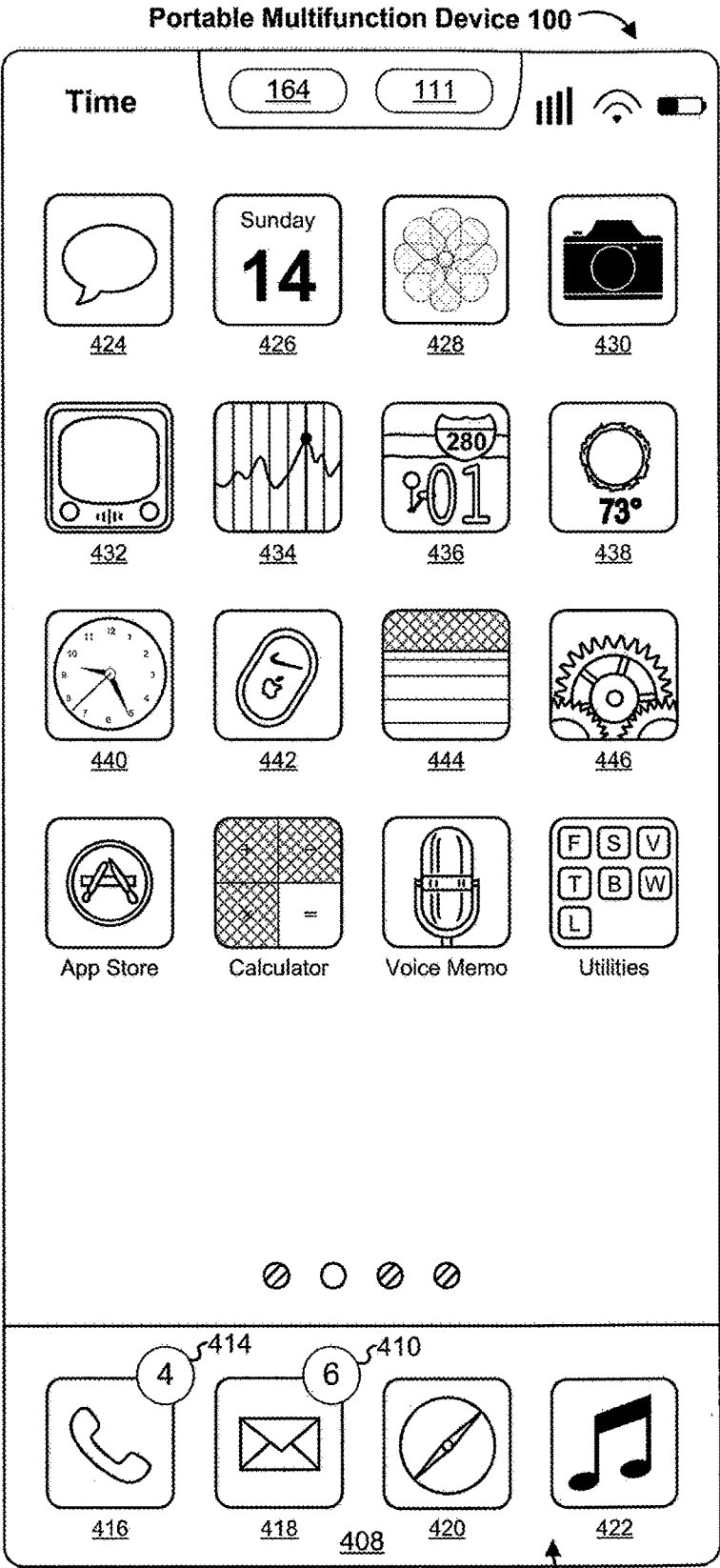


Figure 4A

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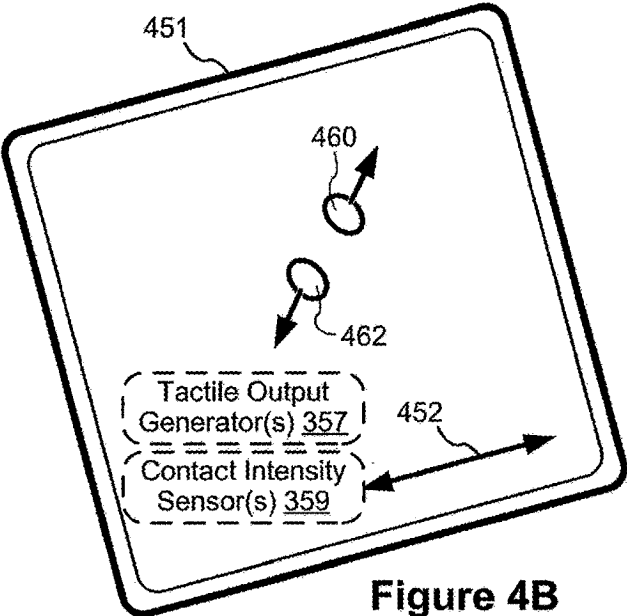
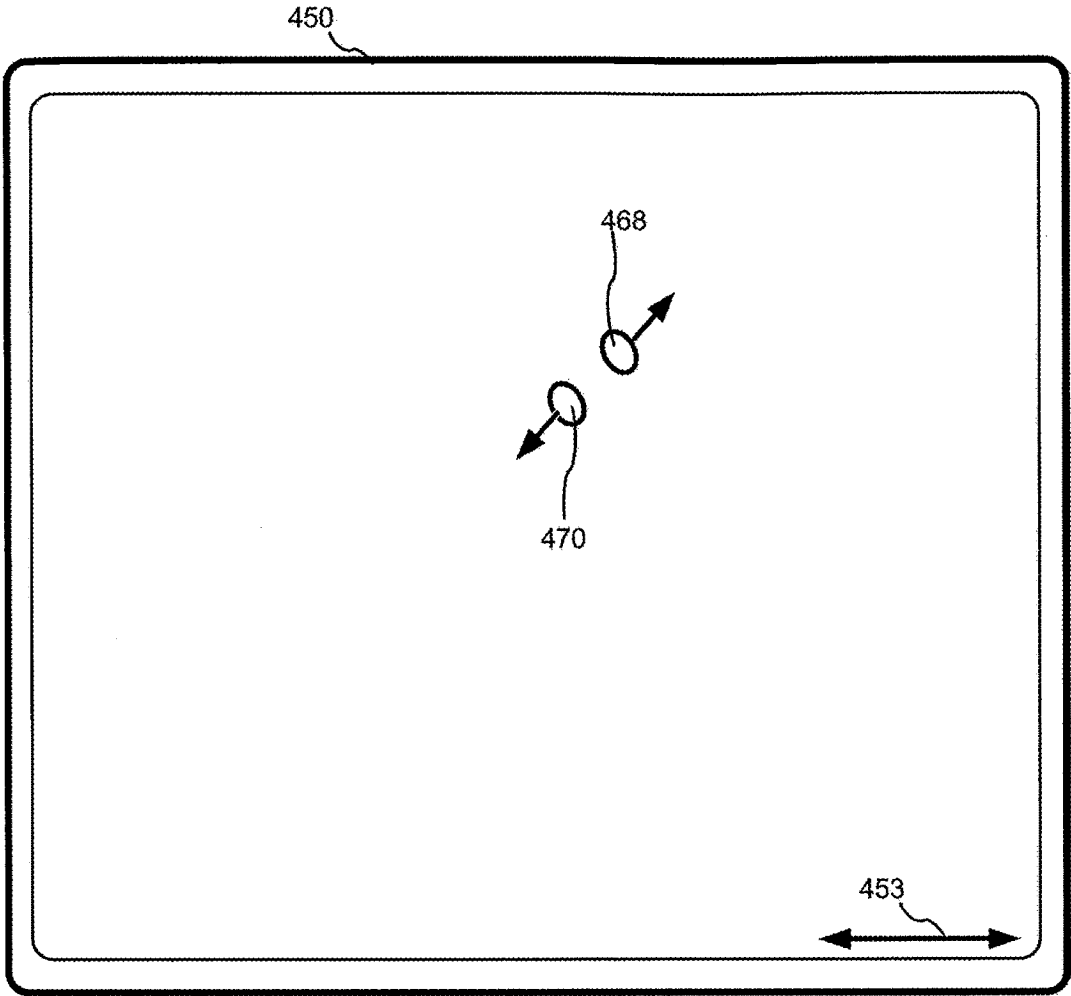


Figure 4B



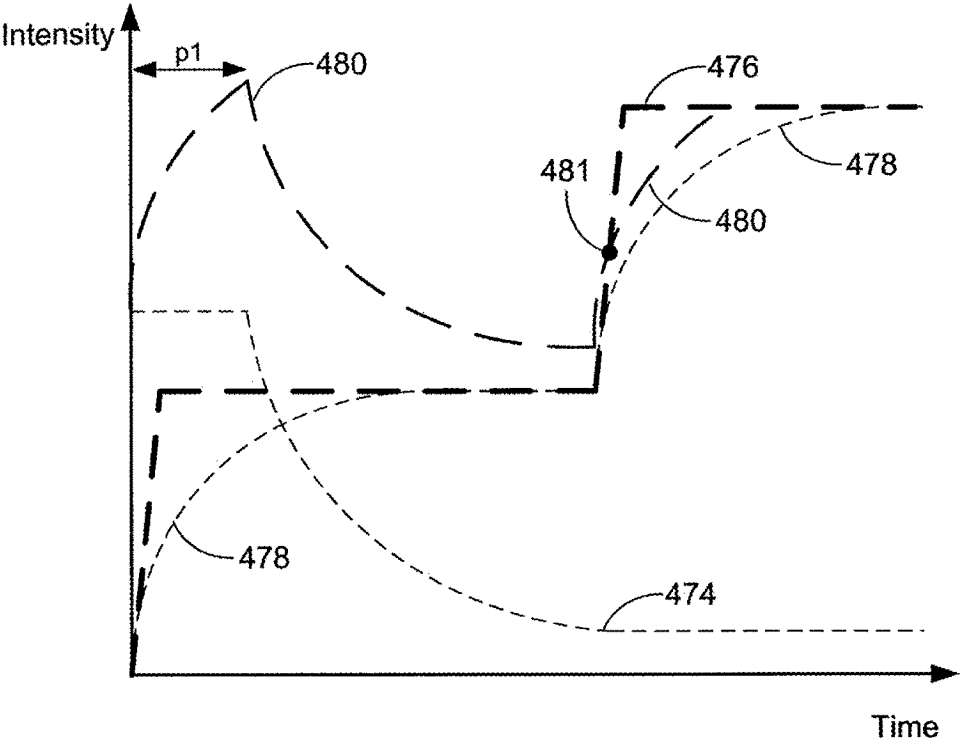


Figure 4C

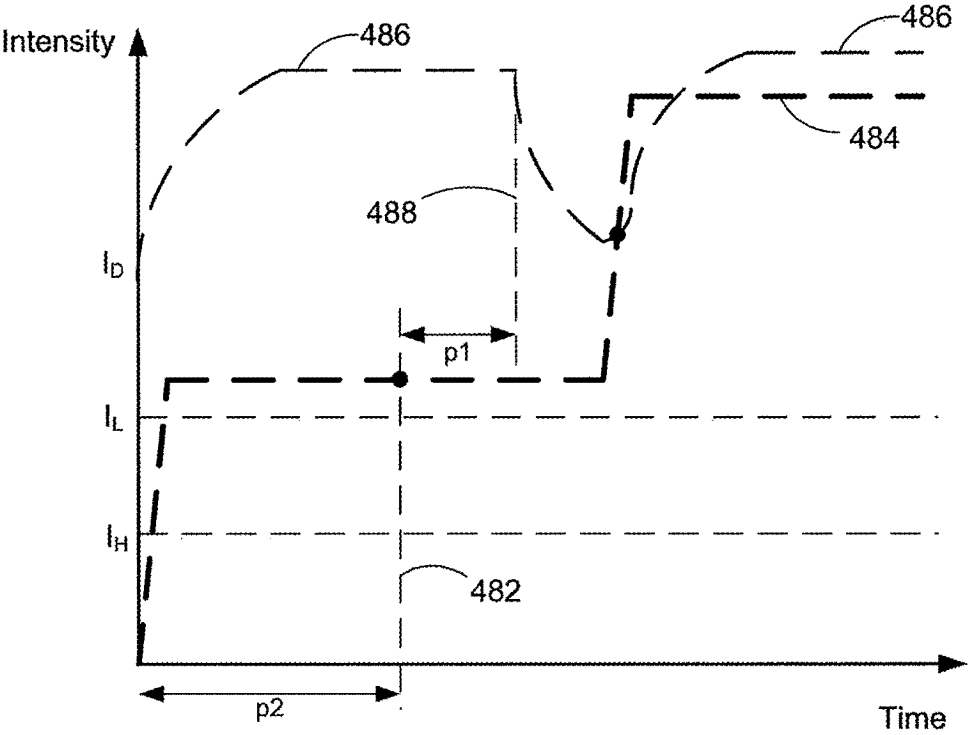


Figure 4D

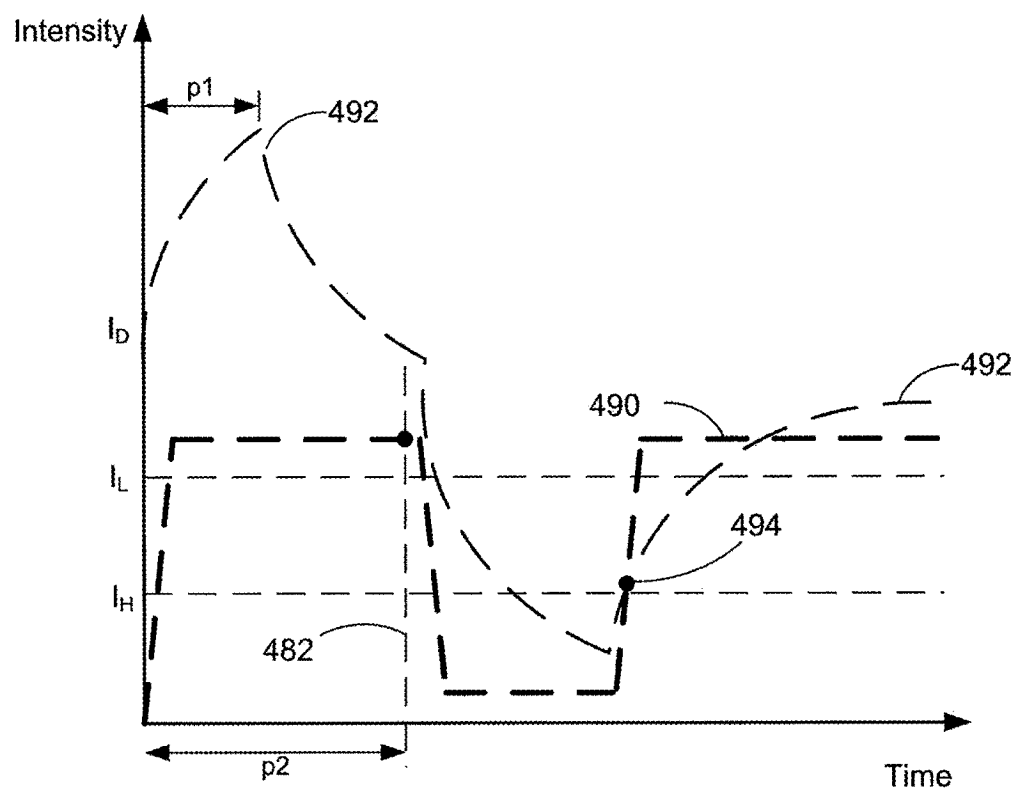


Figure 4E

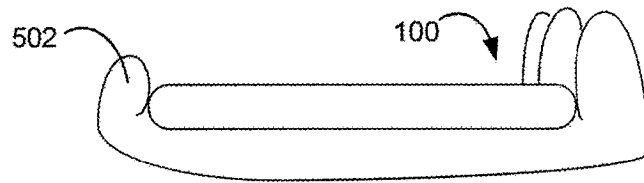


Figure 5A1

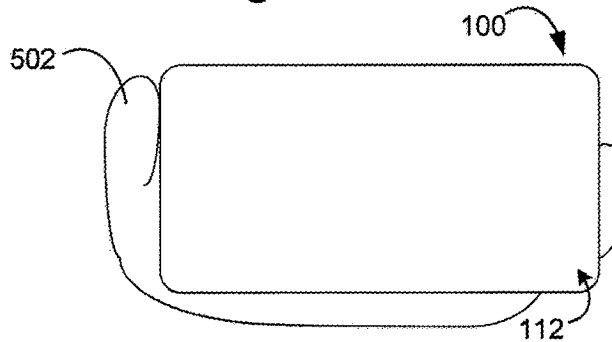


Figure 5A2

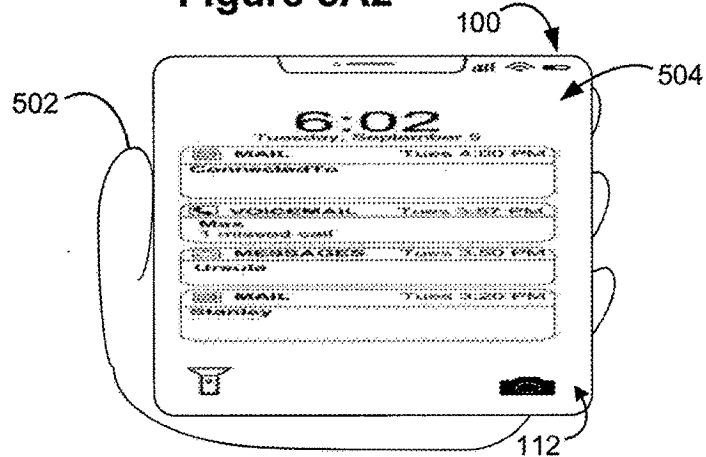


Figure 5A3

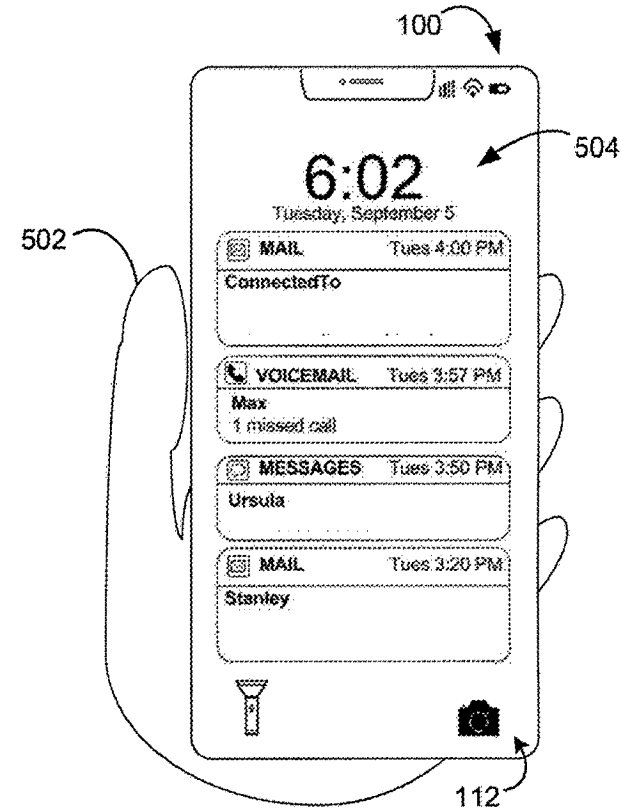


Figure 5A4

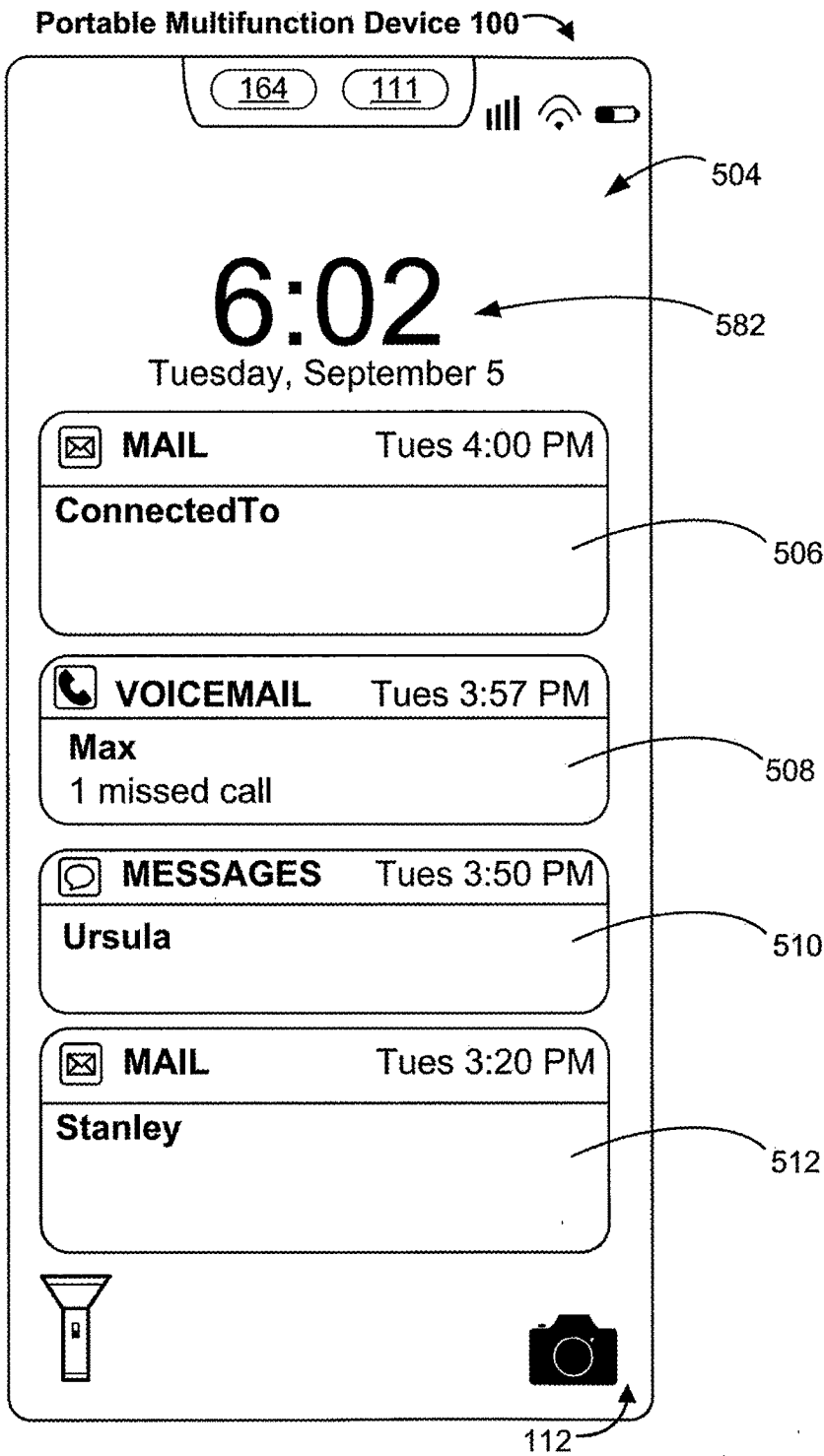


Figure 5B



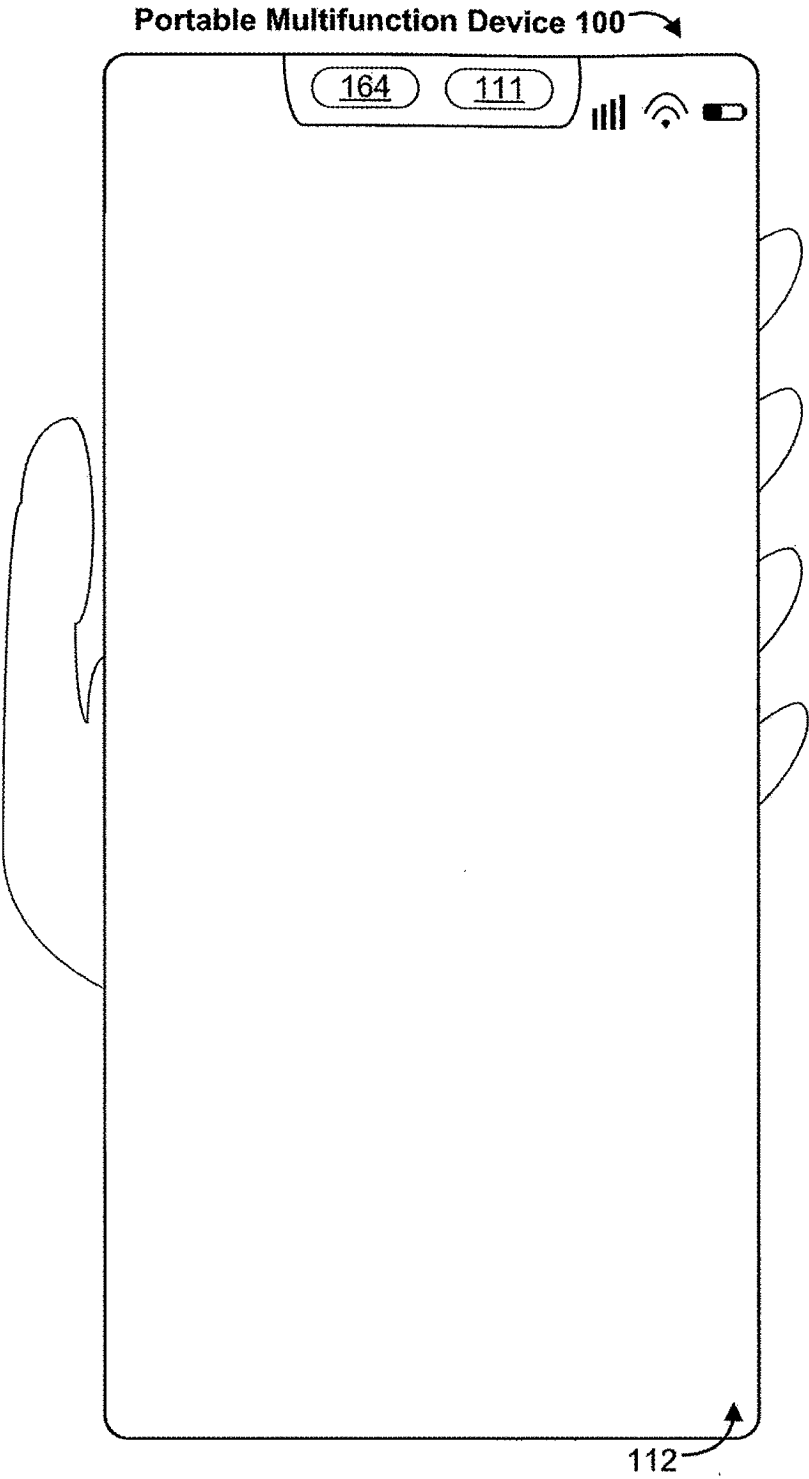


Figure 5C

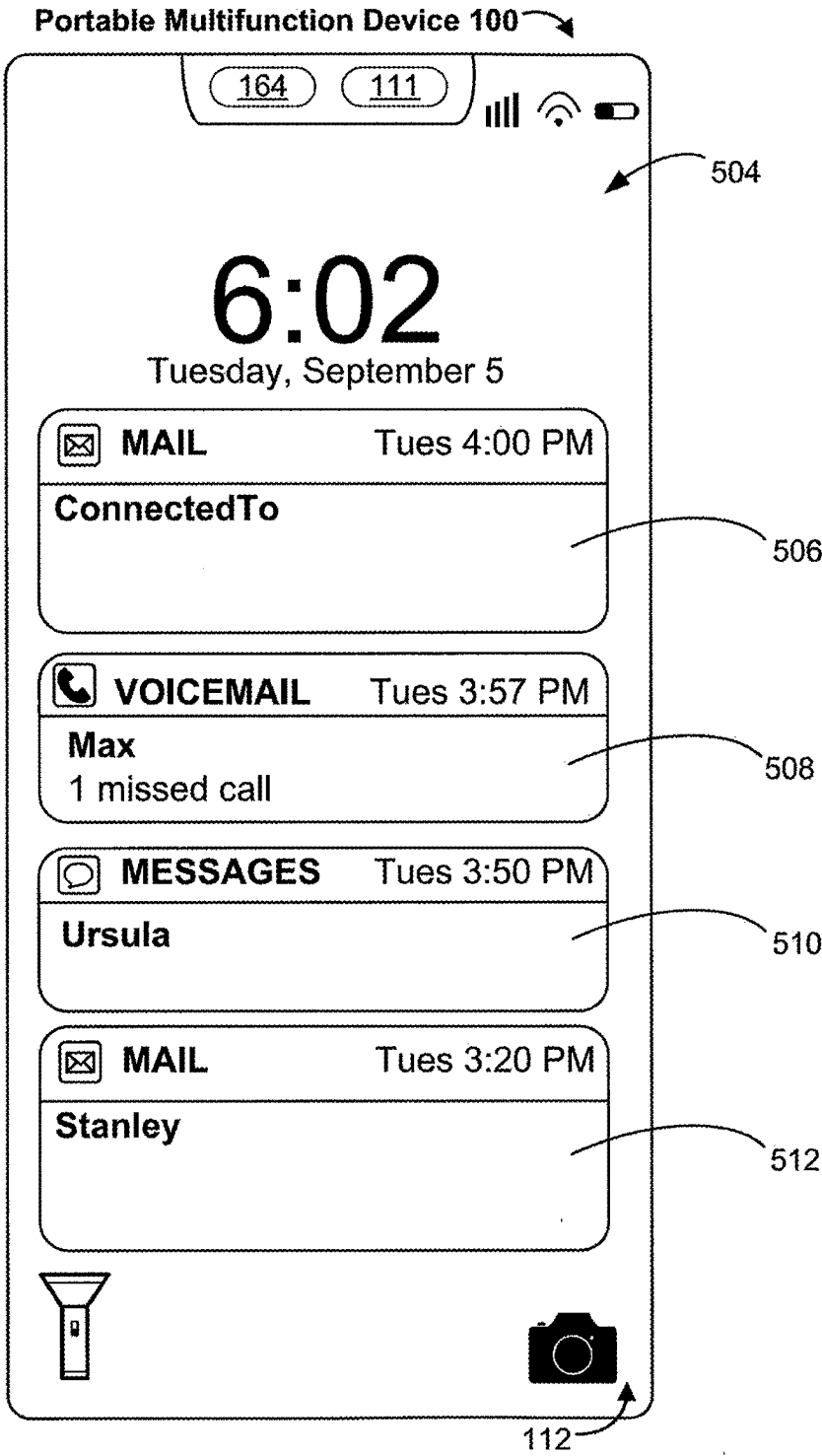


Figure 5D

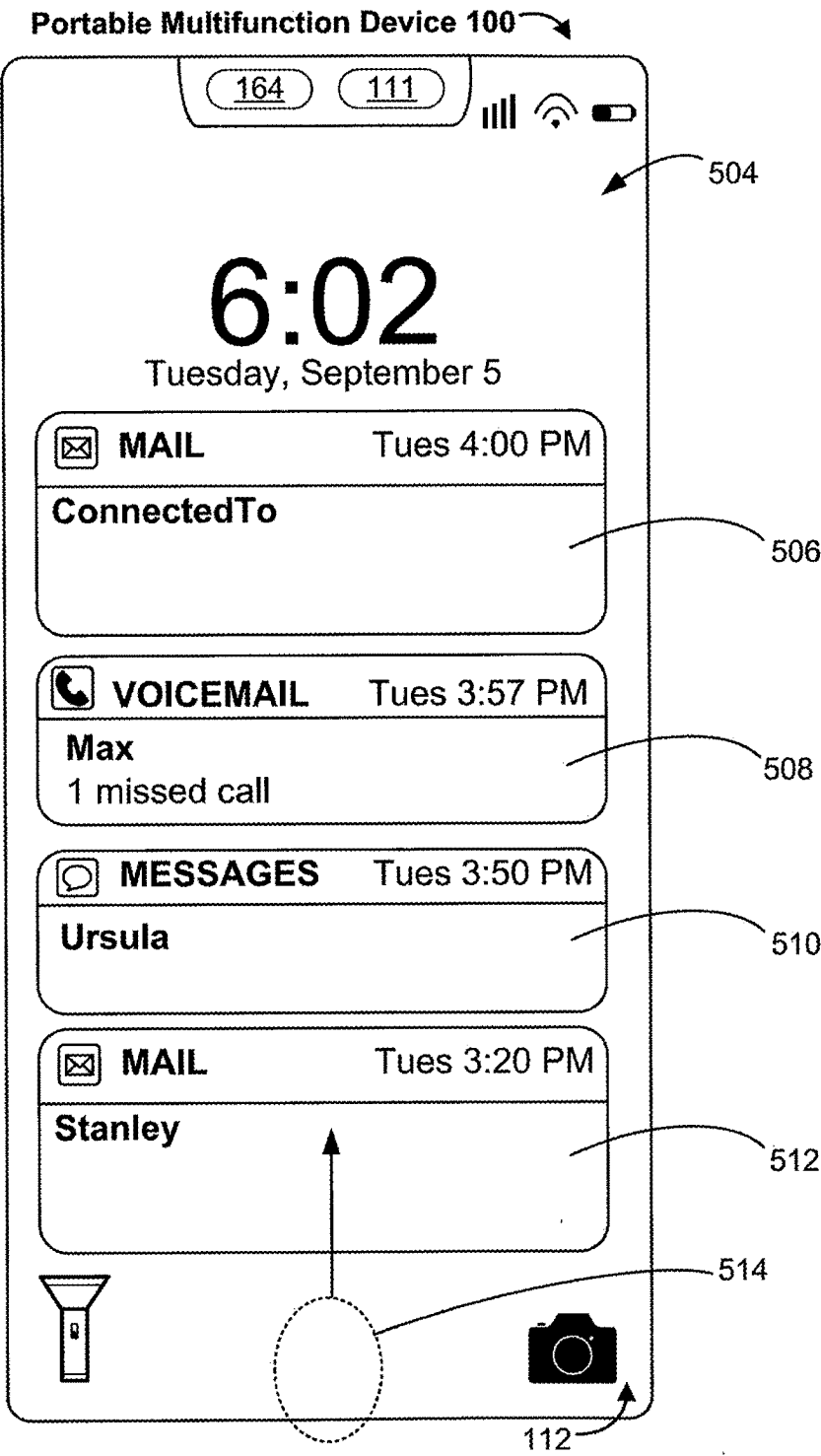


Figure 5E

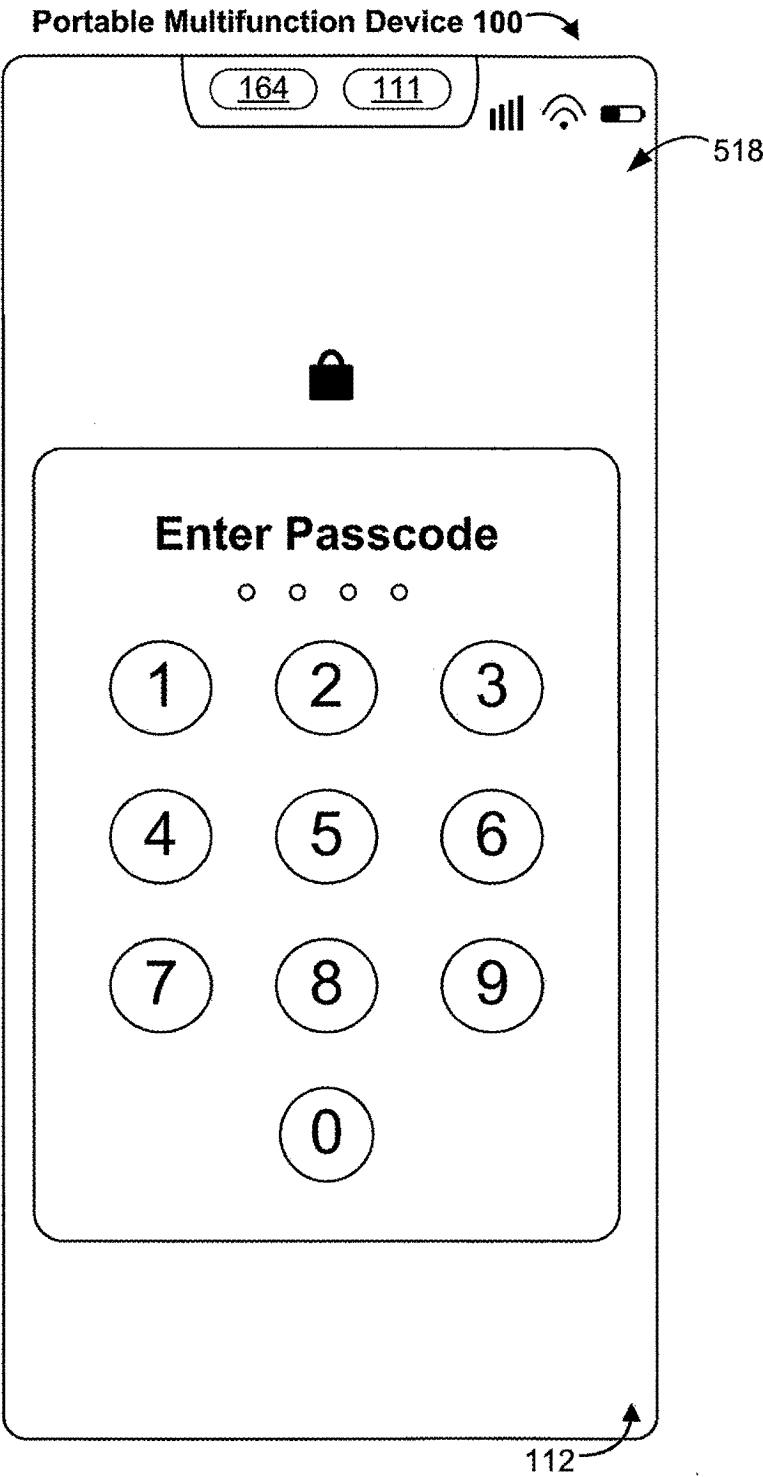


Figure 5F

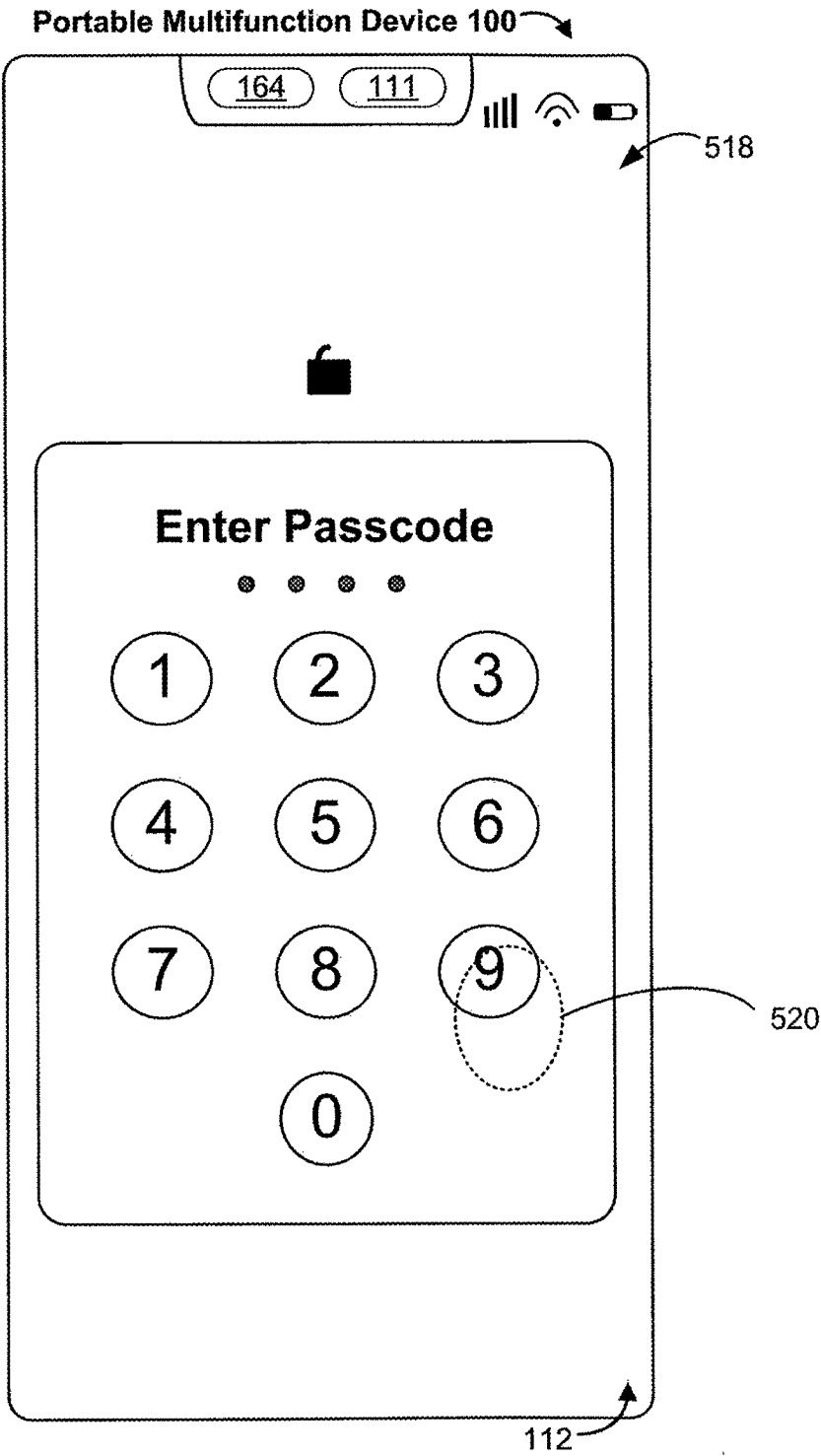


Figure 5G



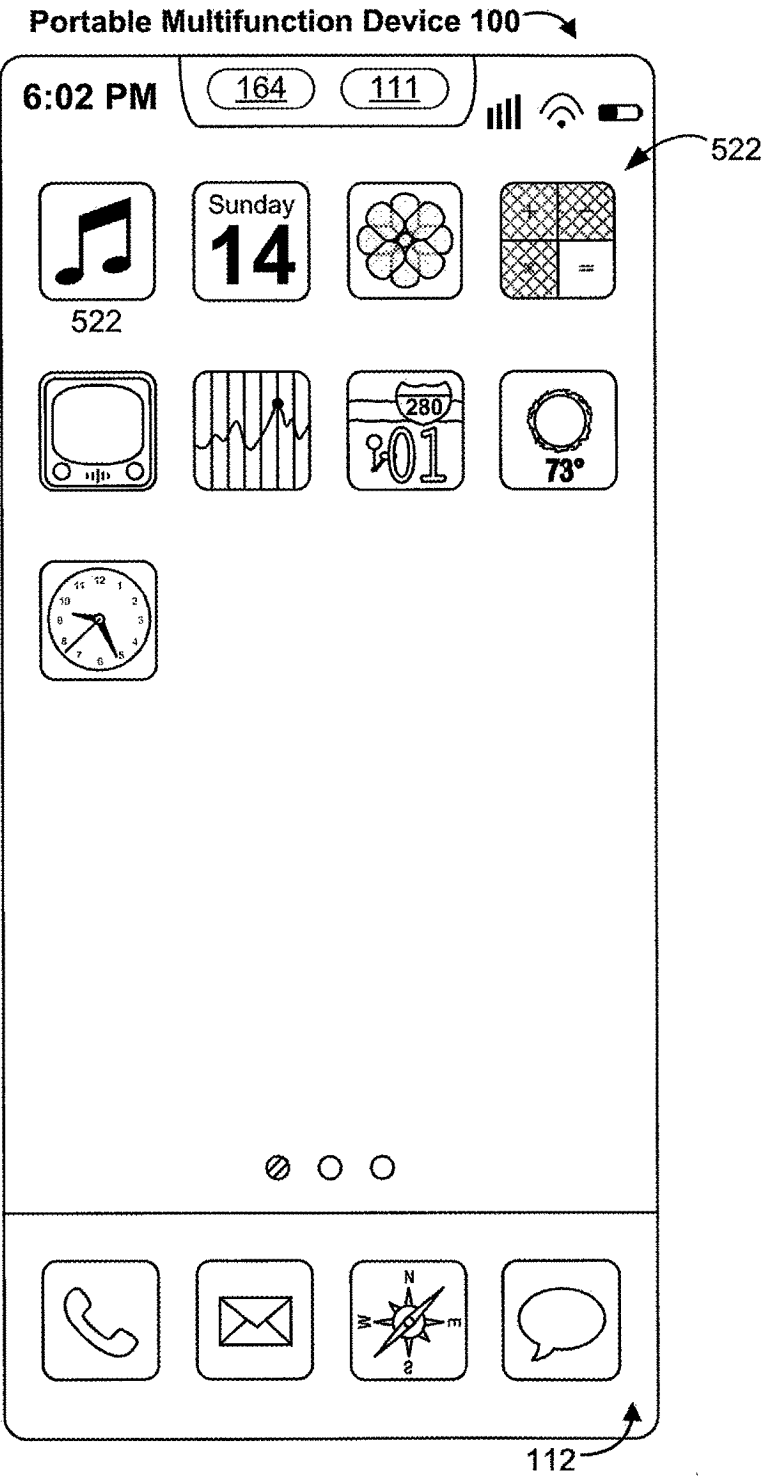


Figure 5H

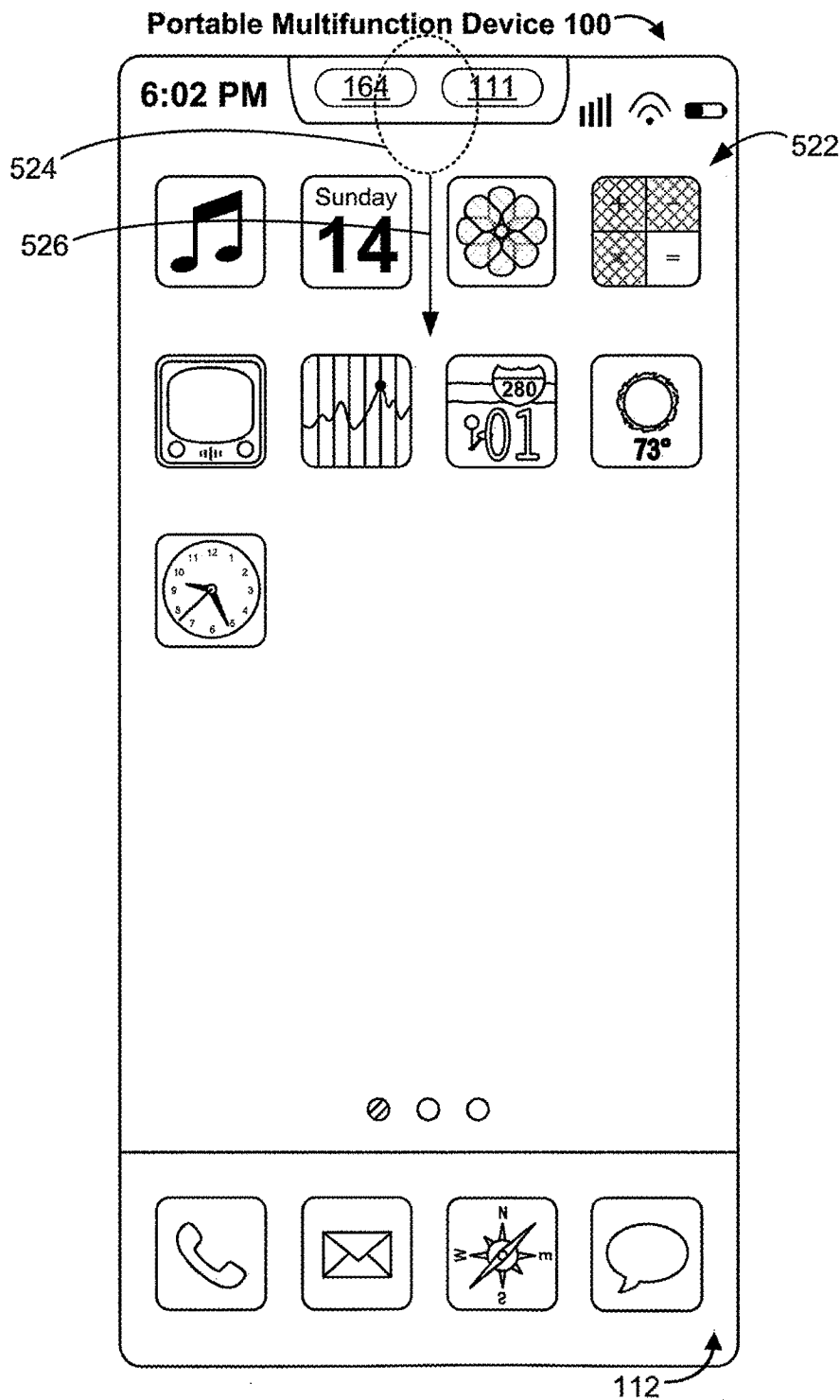


Figure 5l

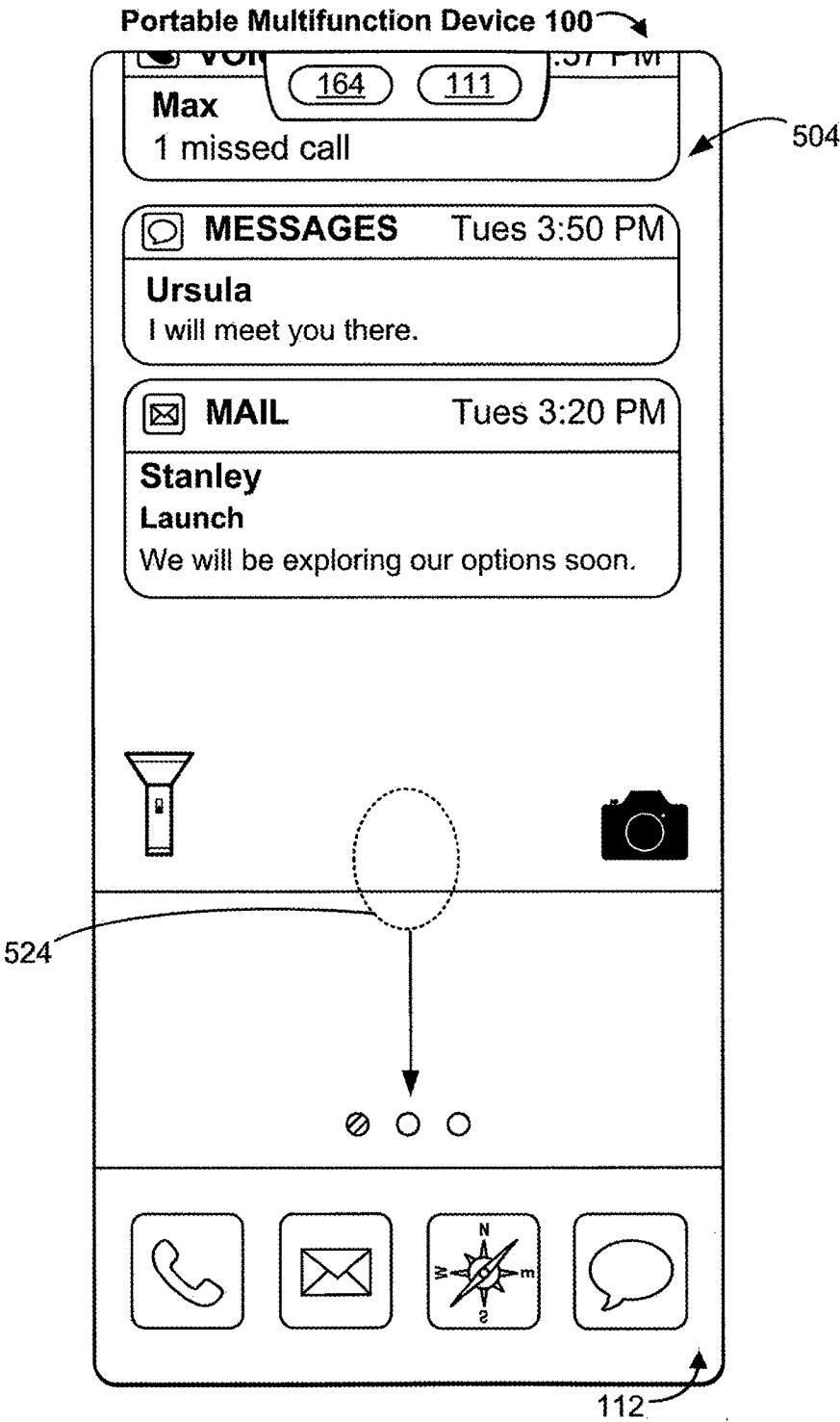


Figure 5J

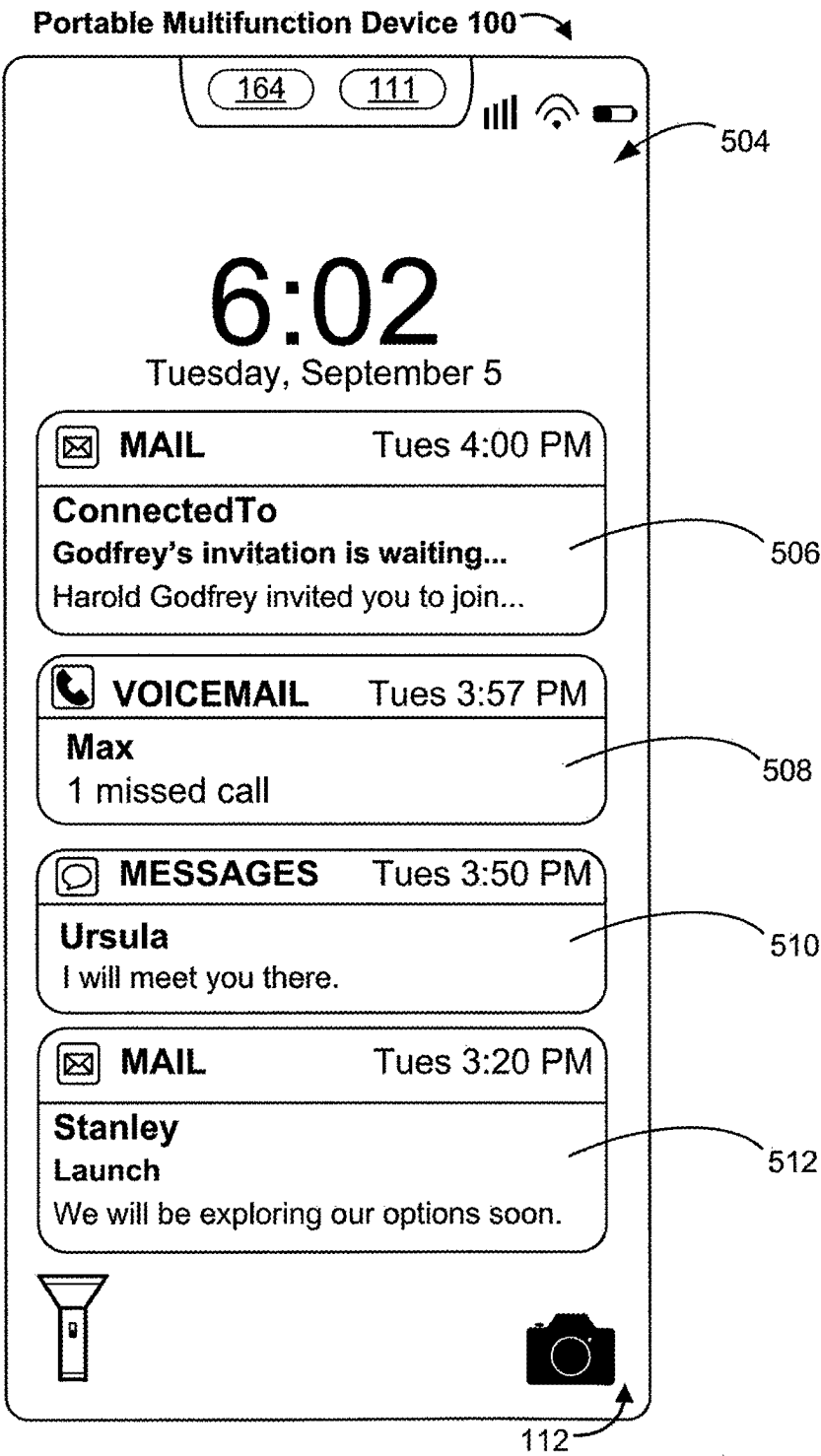


Figure 5K

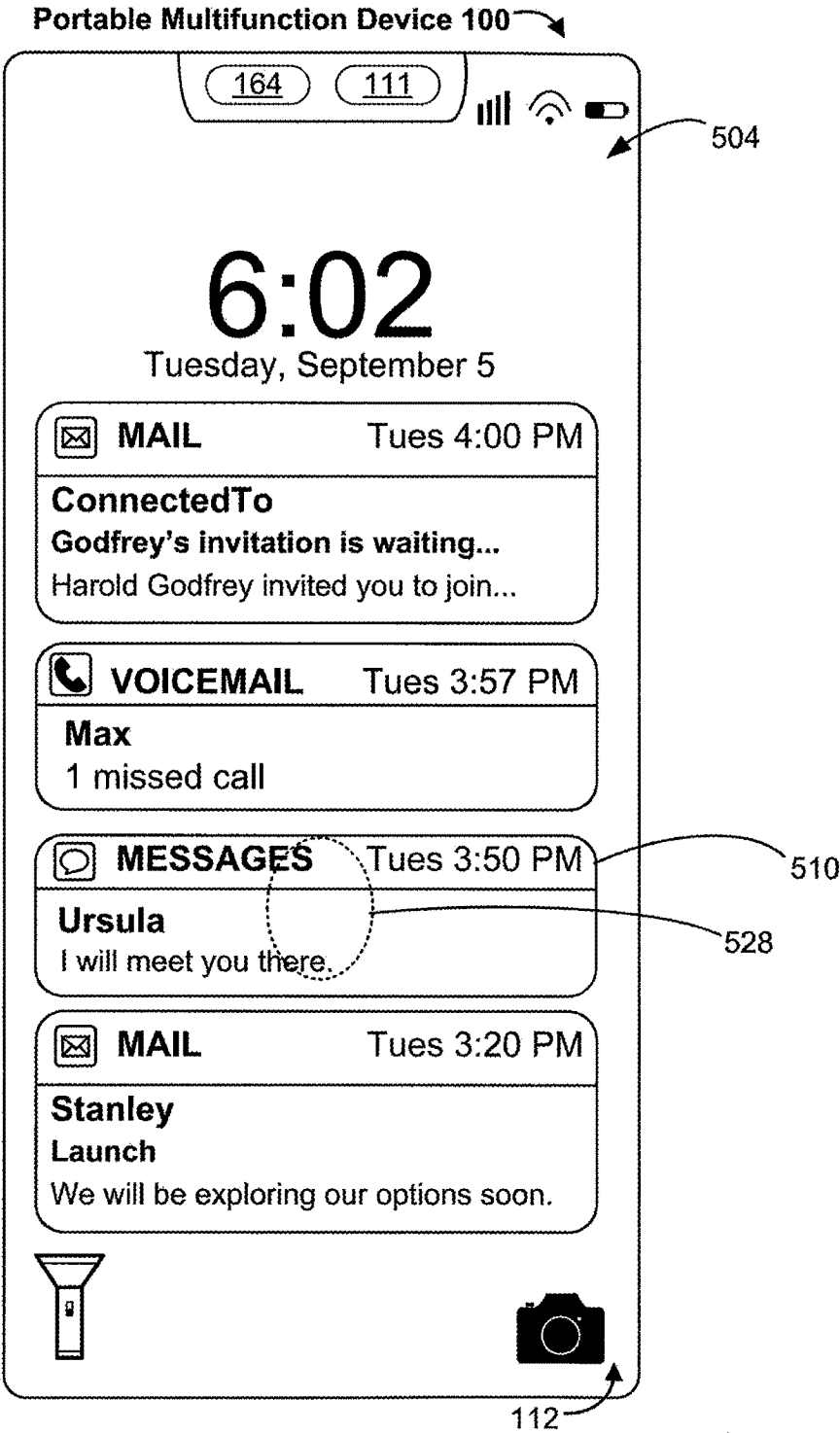


Figure 5L



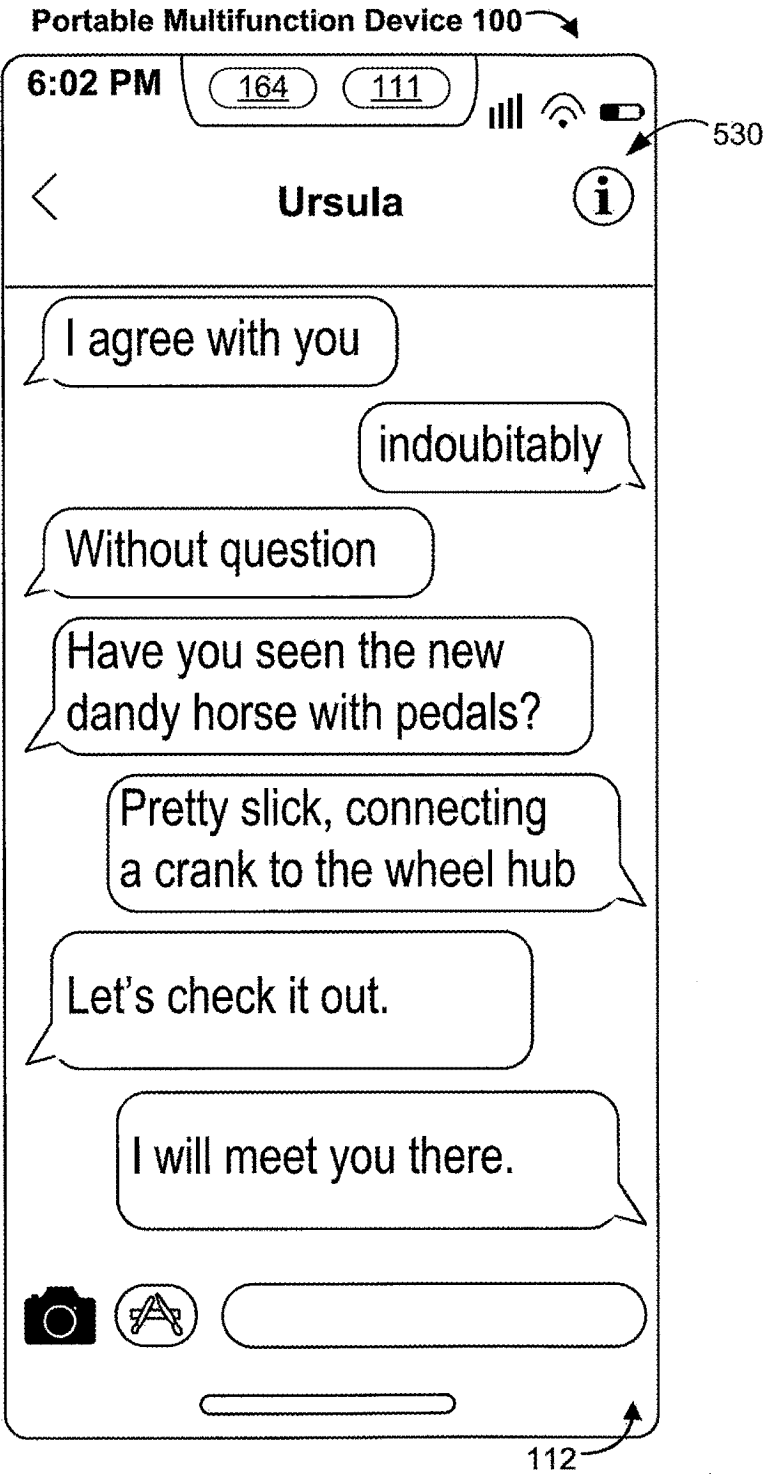


Figure 5M

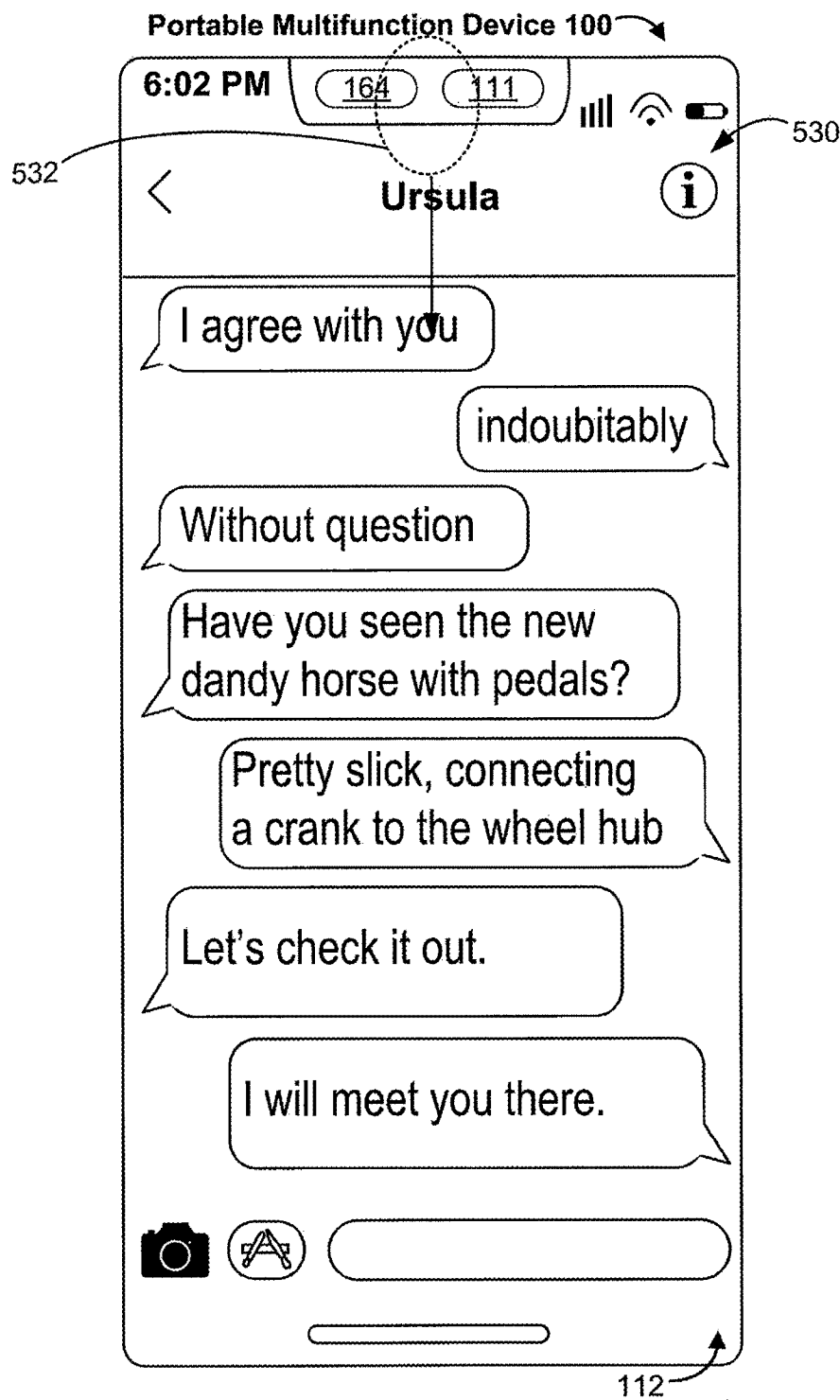


Figure 5N

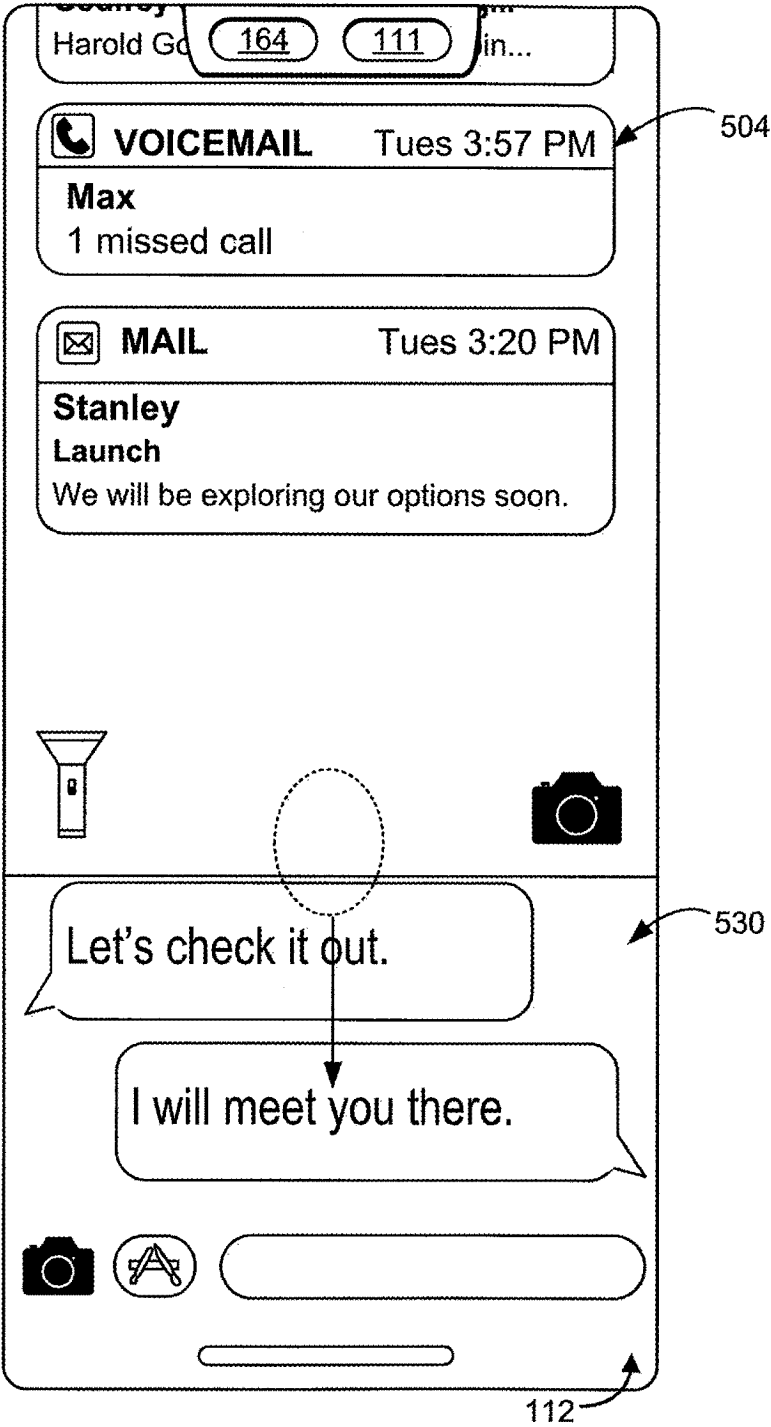


Figure 50

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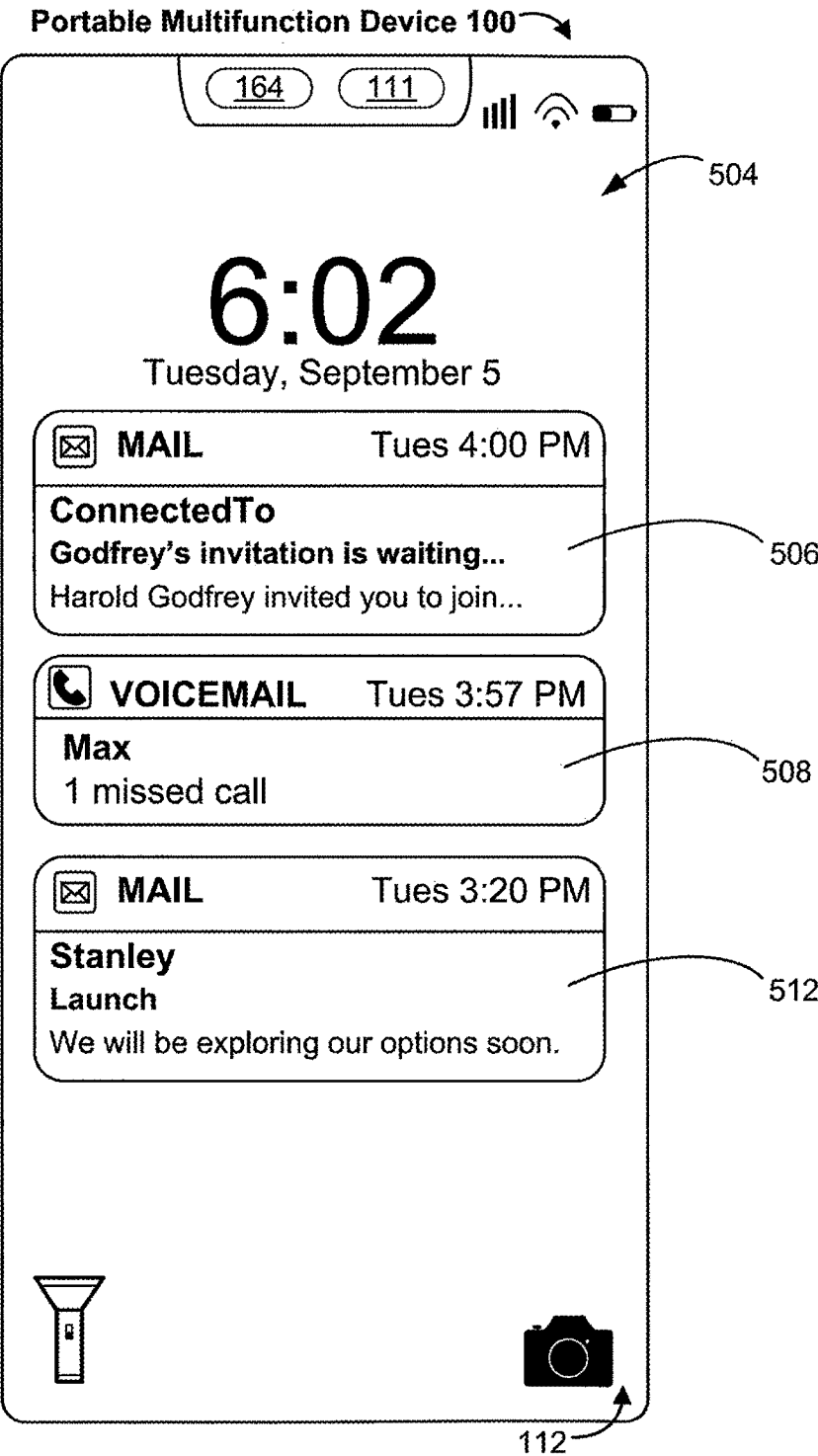


Figure 5P

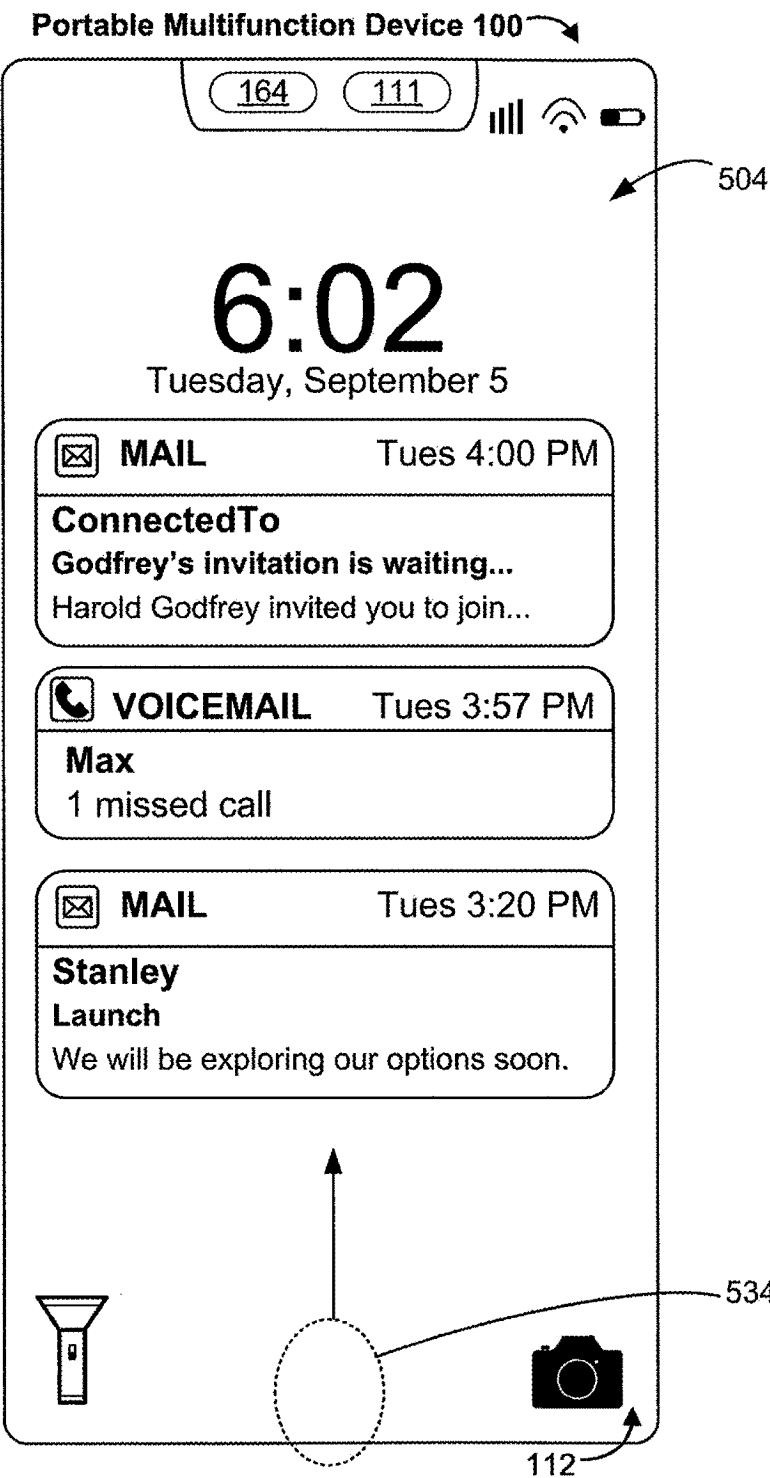


Figure 5Q



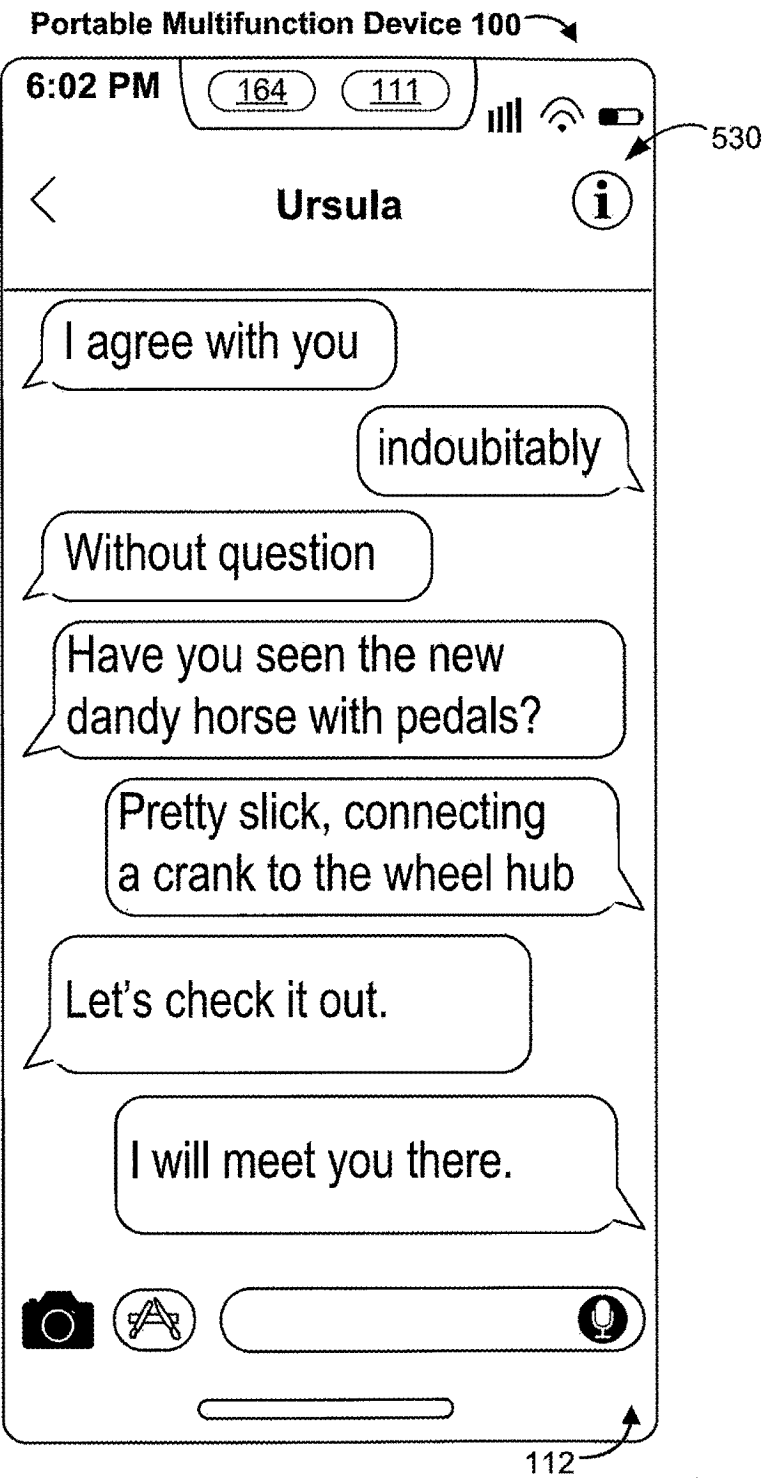


Figure 5R

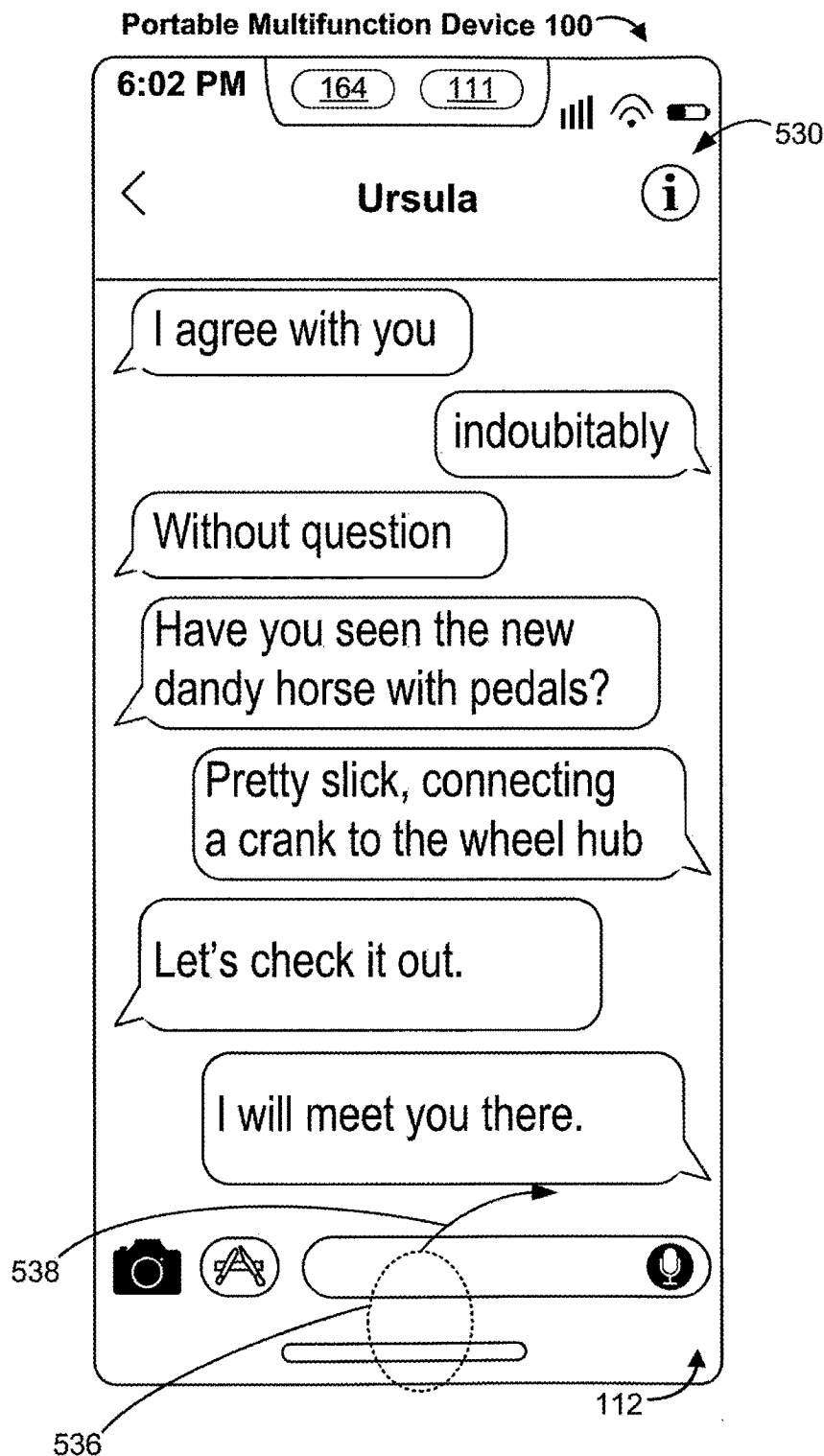


Figure 5S

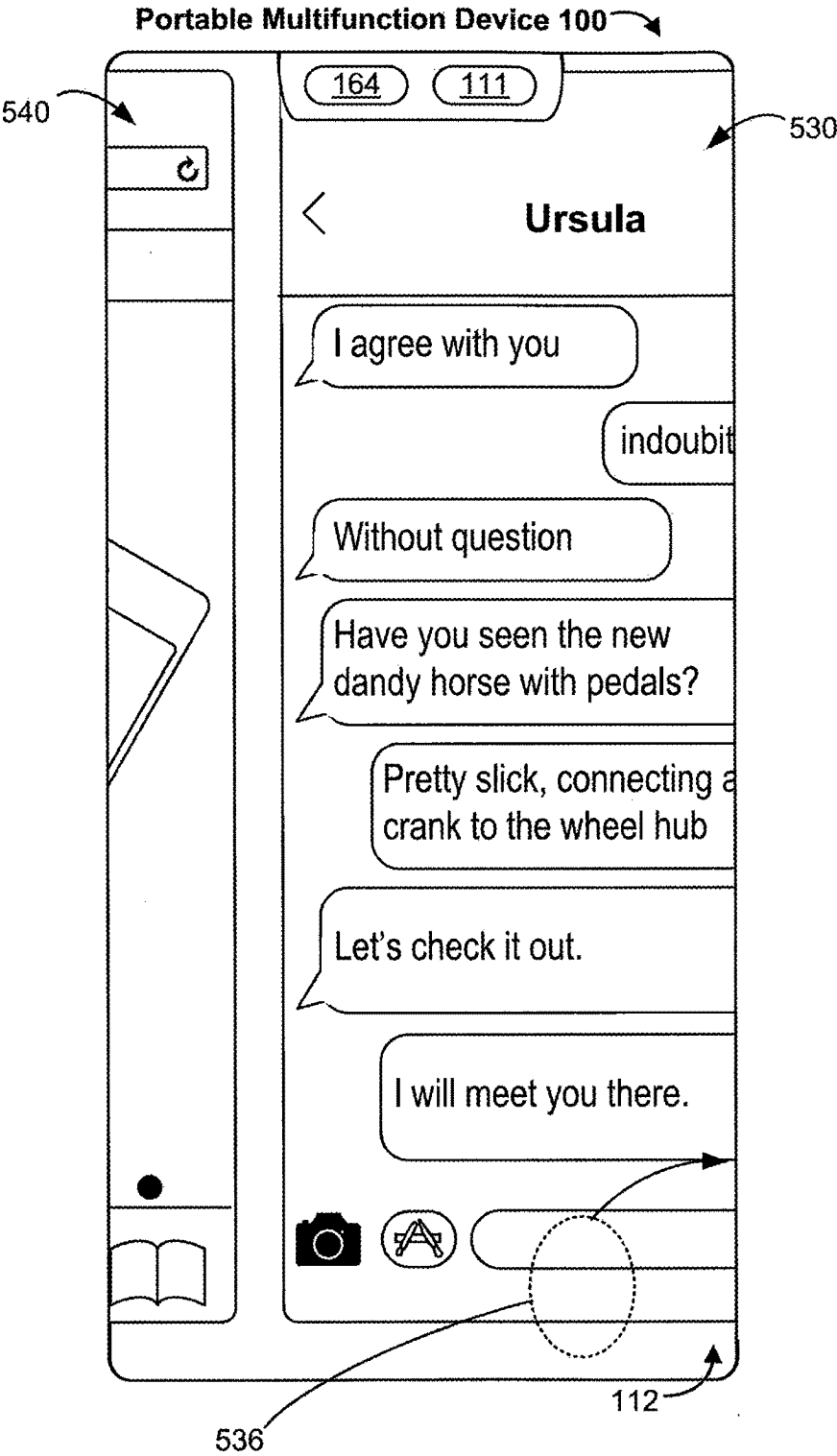


Figure 5T

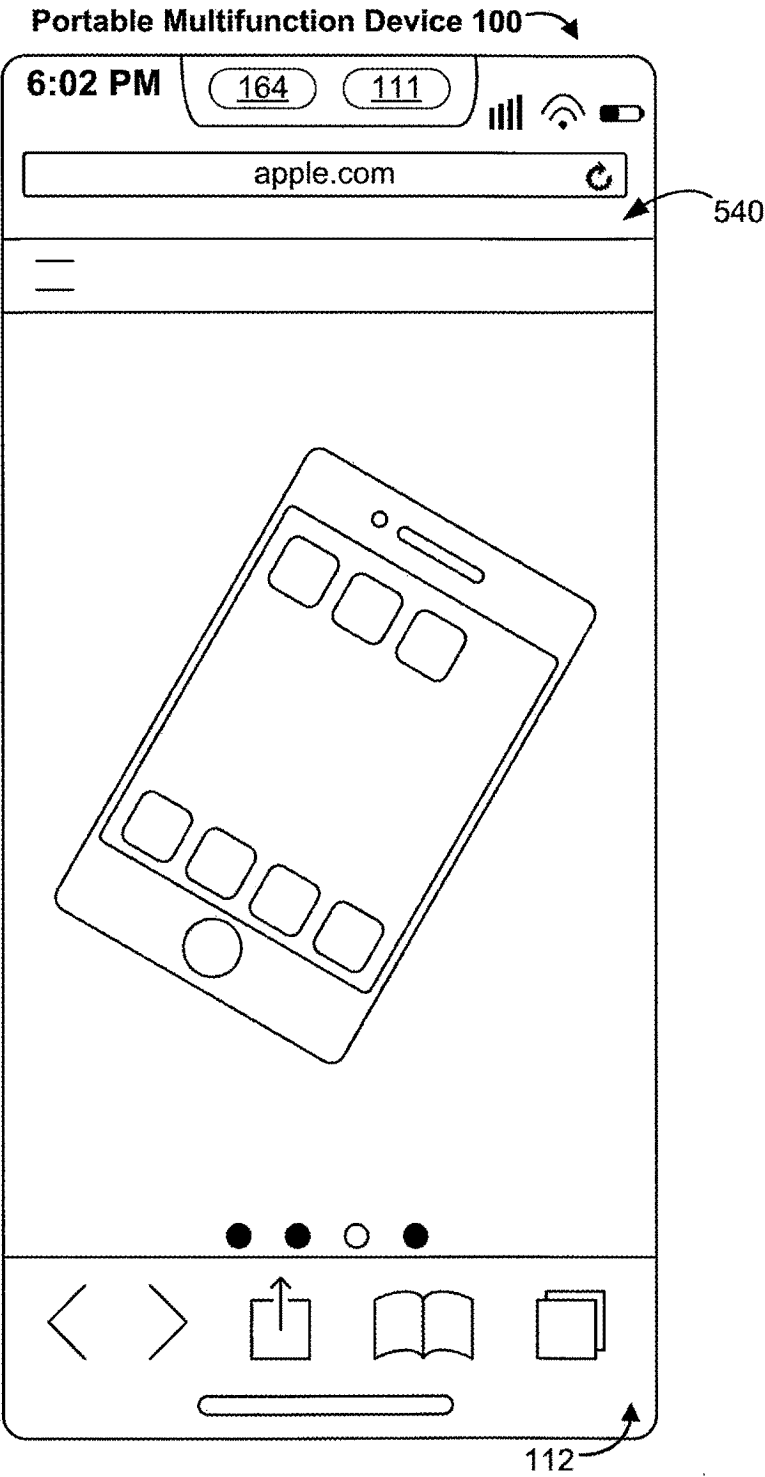


Figure 5U

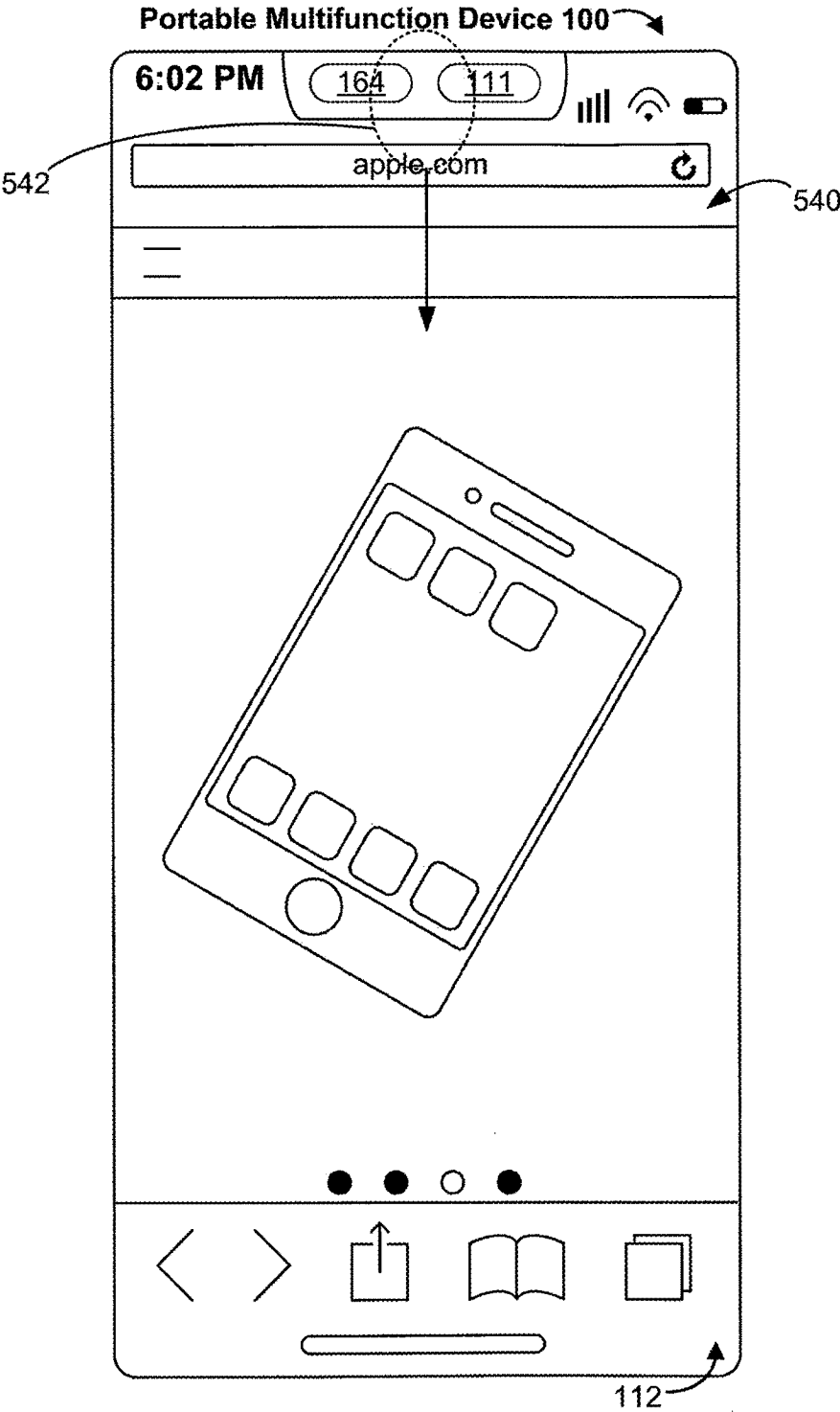


Figure 5V



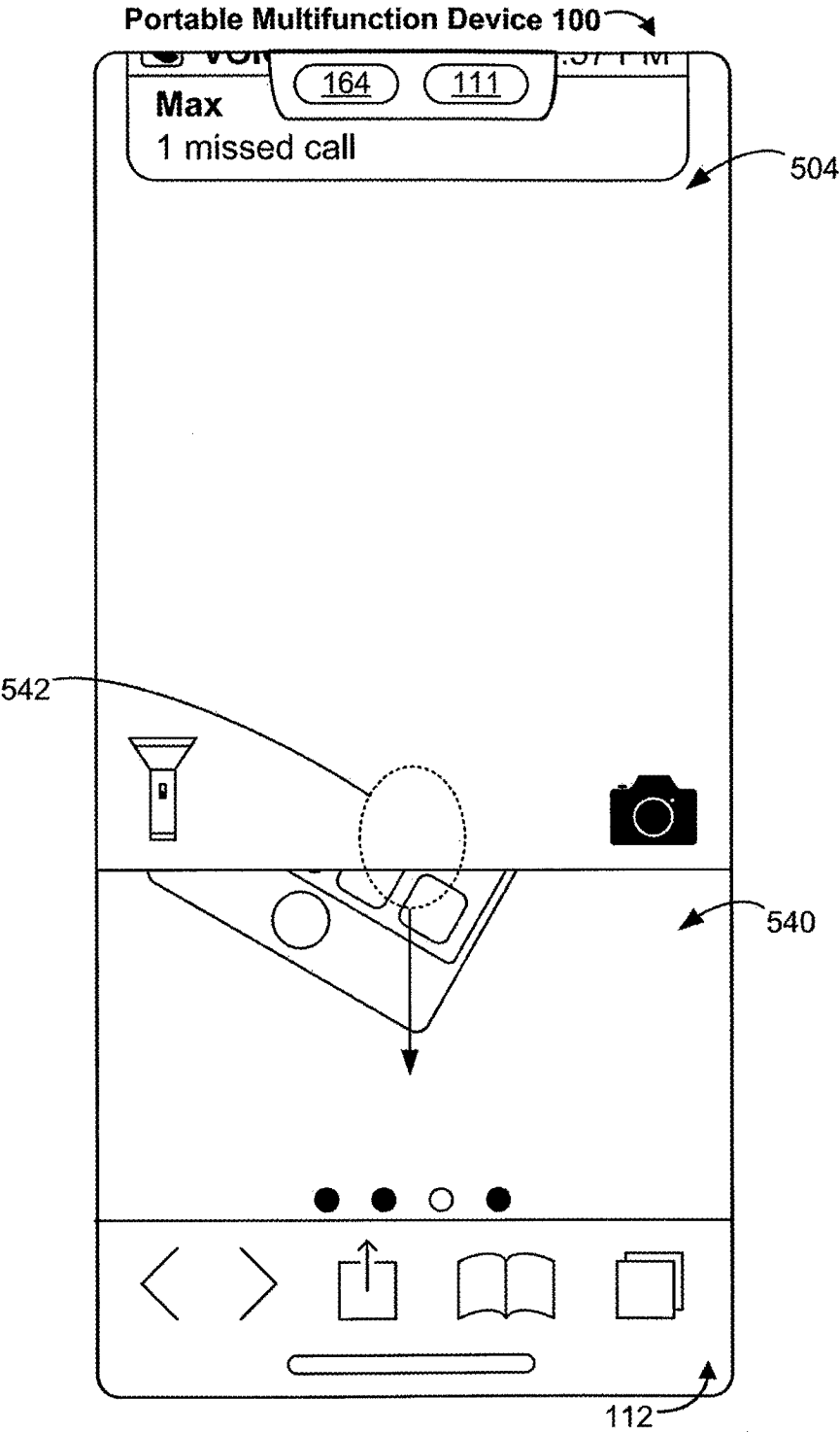


Figure 5W

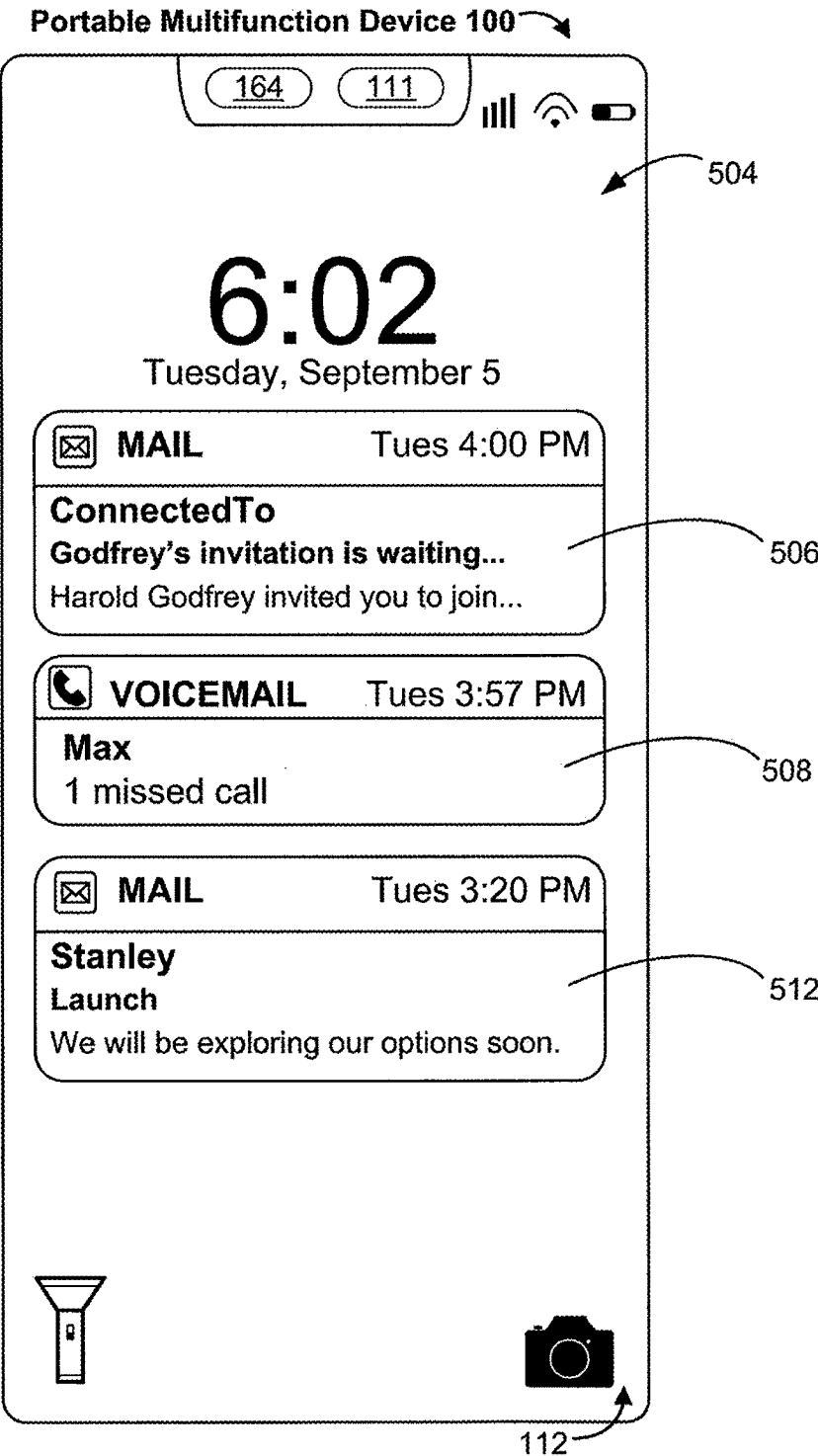


Figure 5X

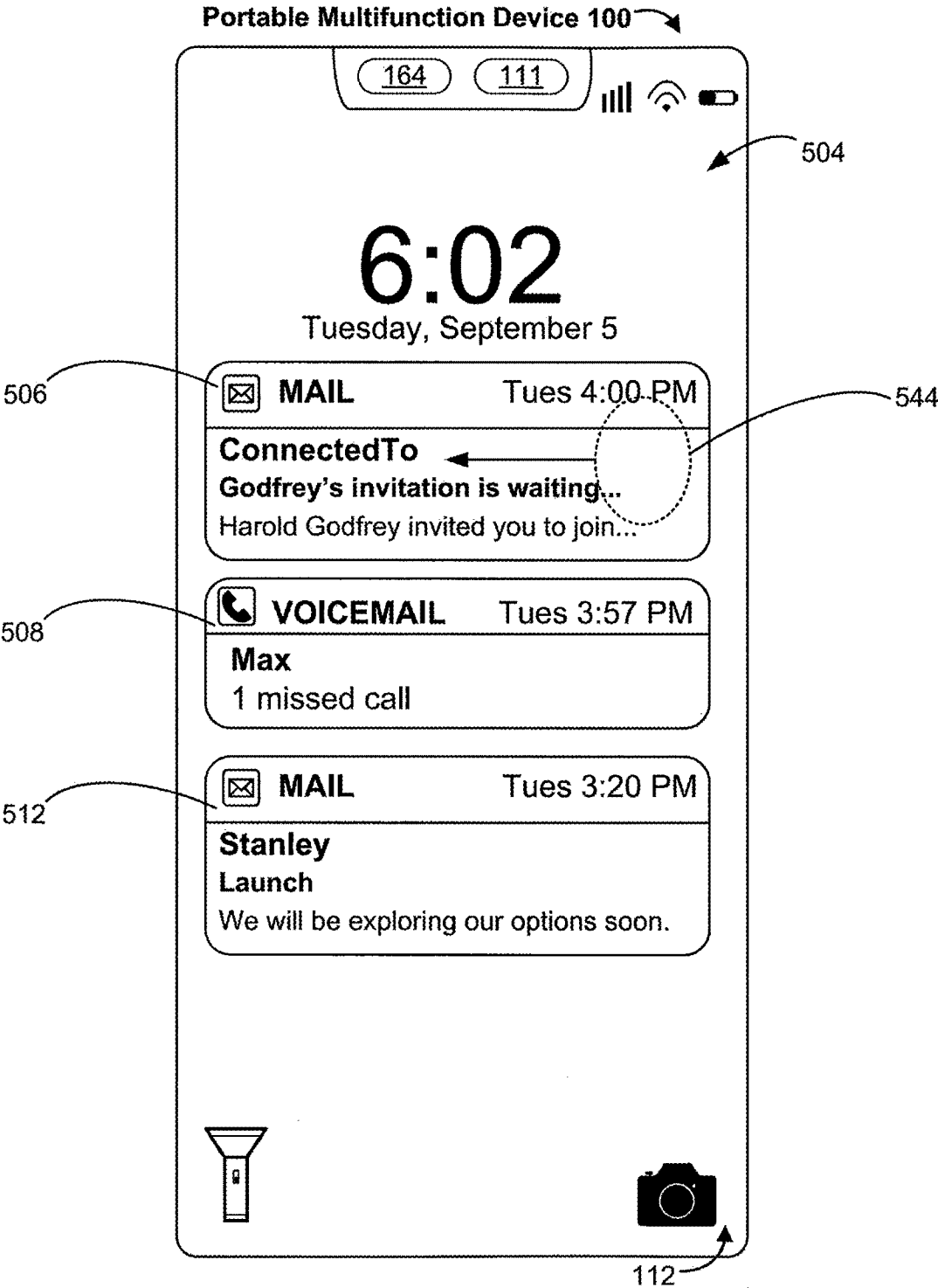


Figure 5Y

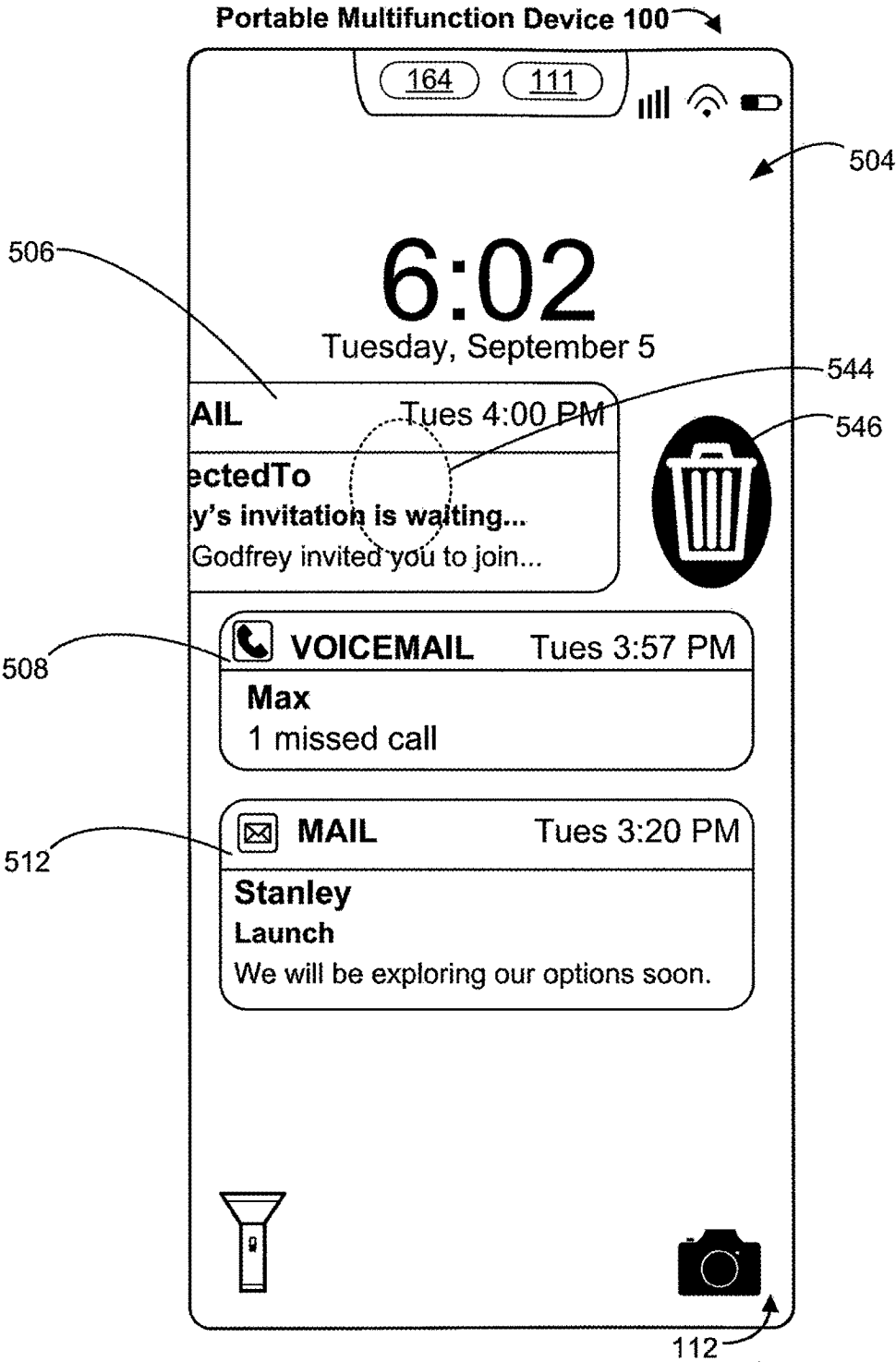


Figure 5Z

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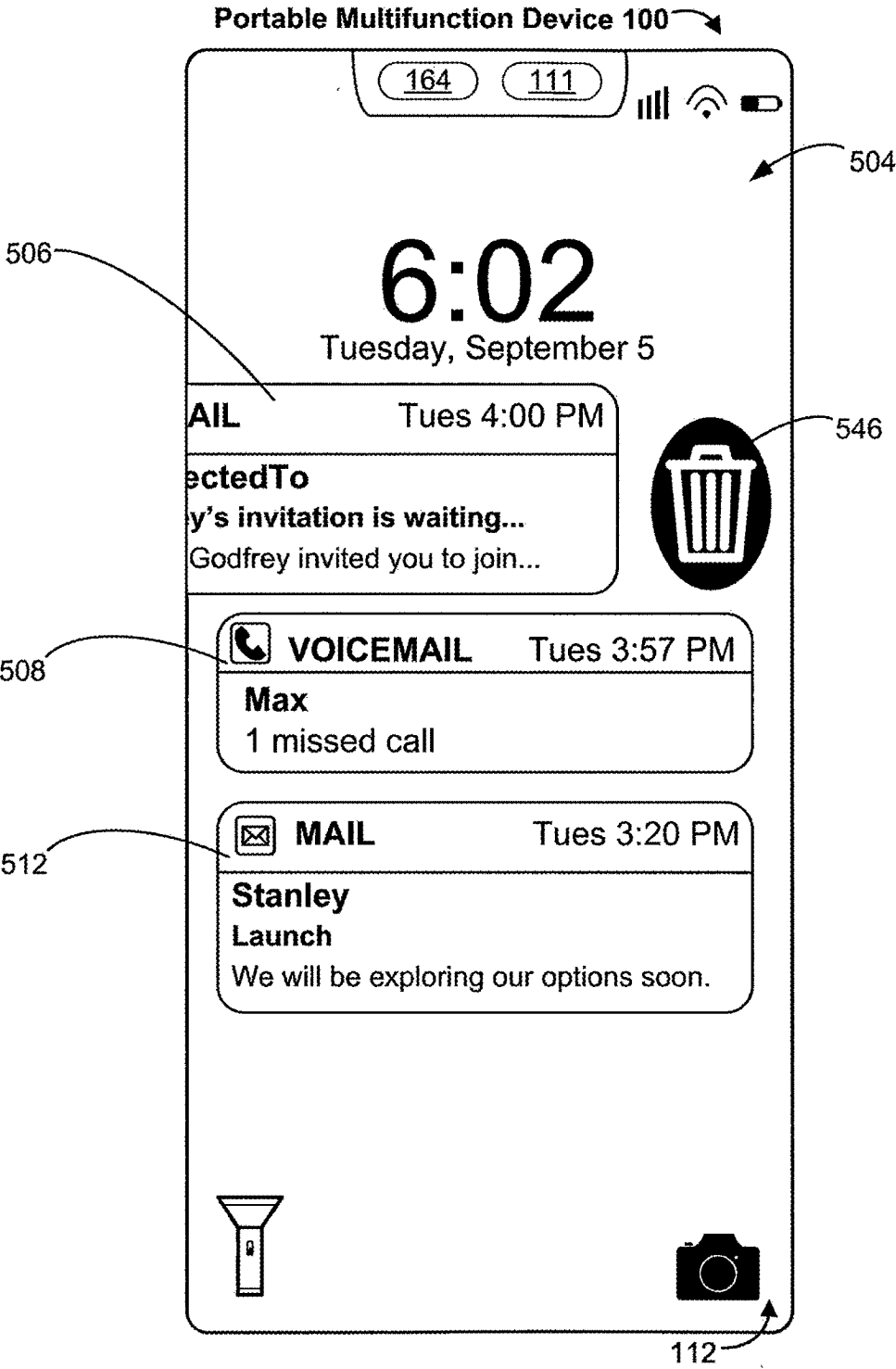


Figure 5AA



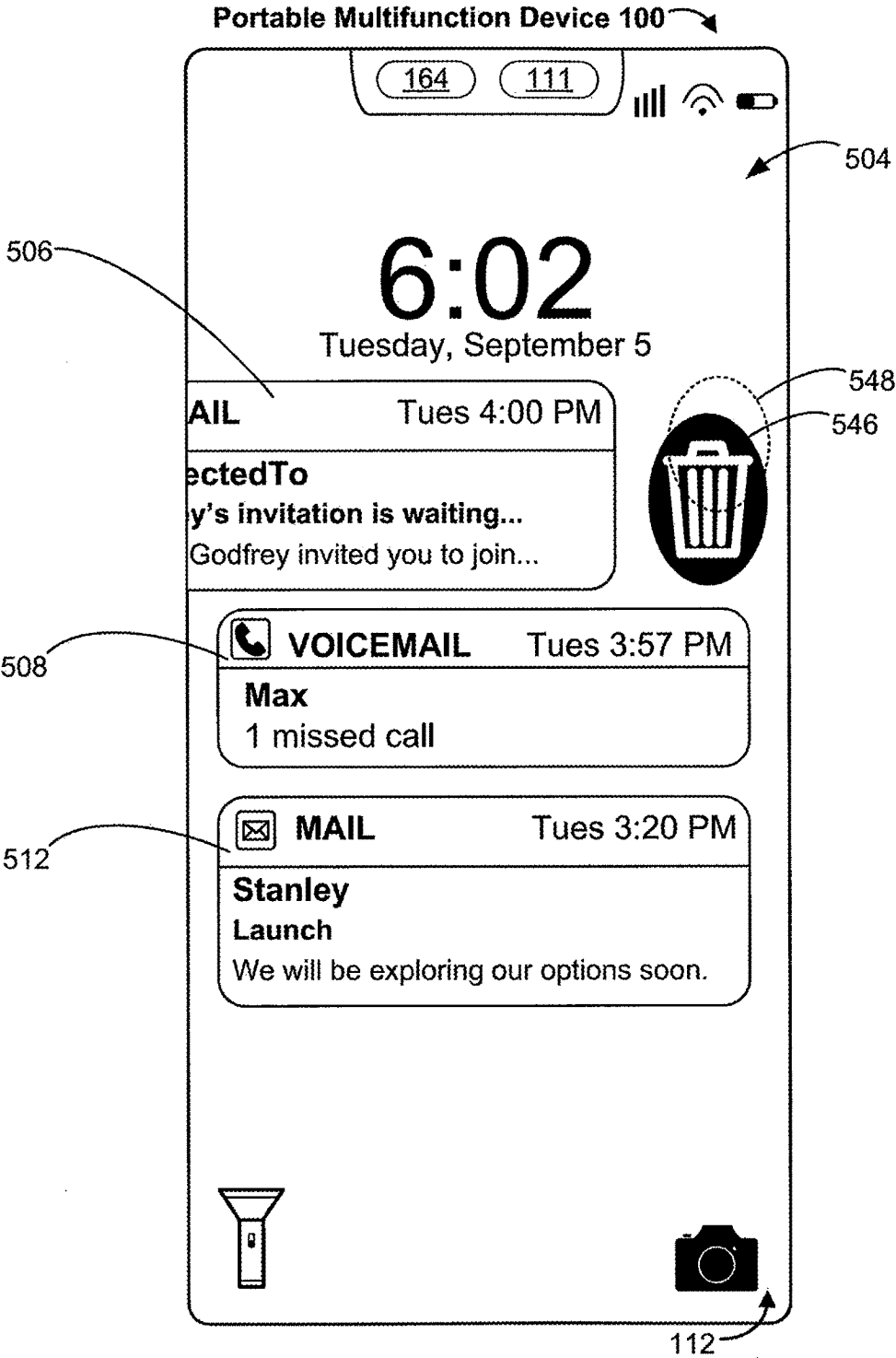


Figure 5AB

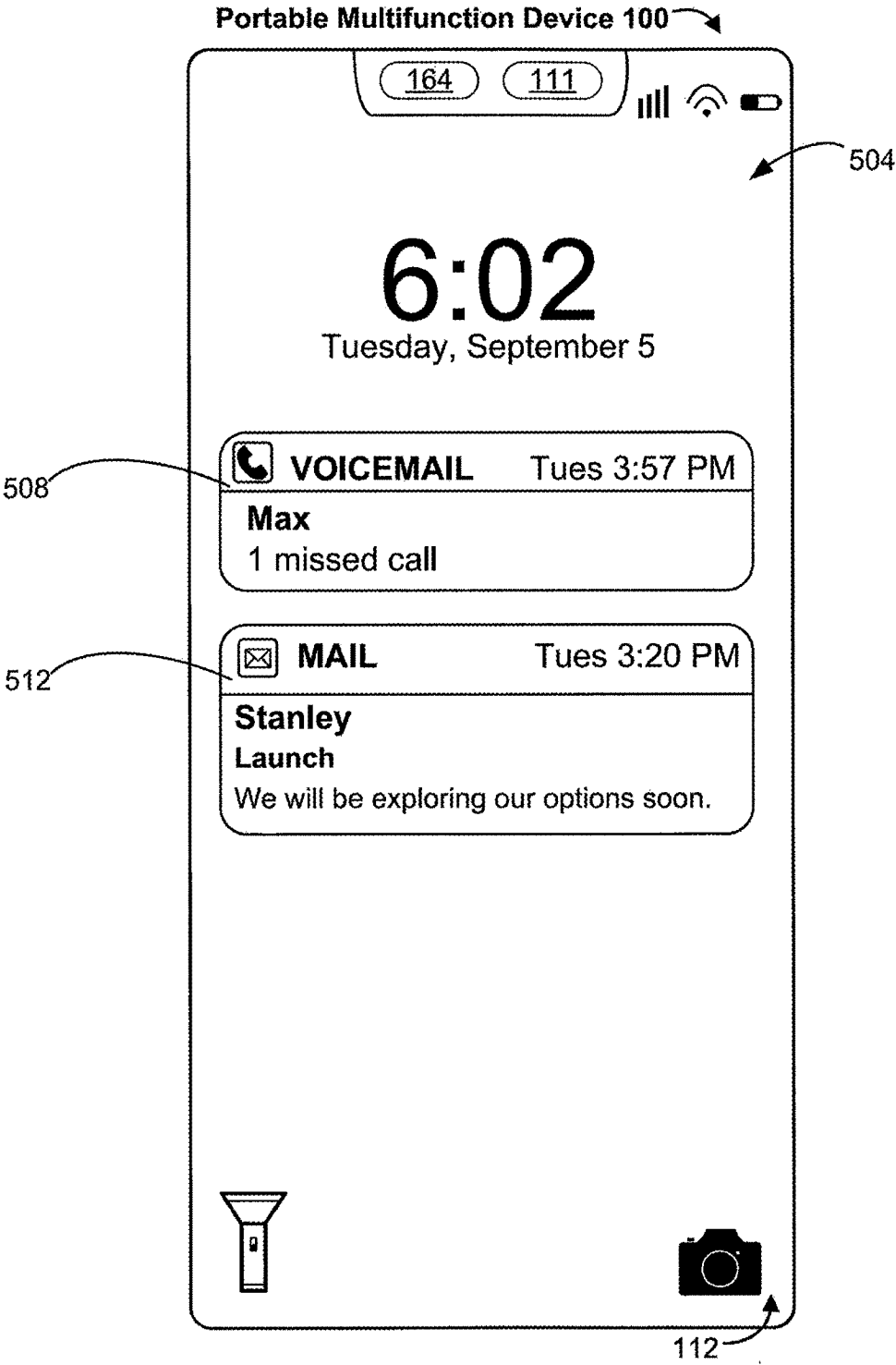


Figure 5AC

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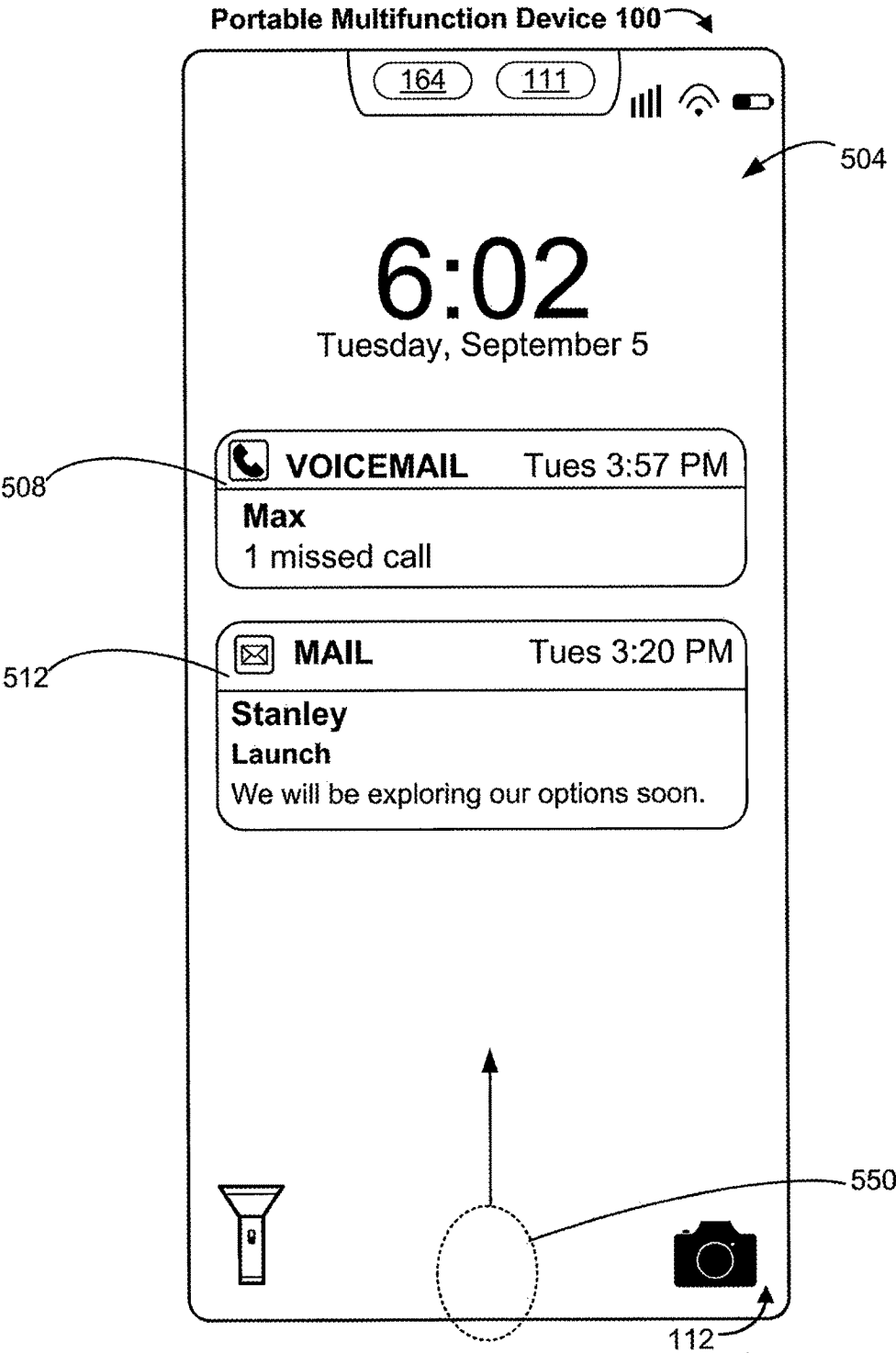


Figure 5AD

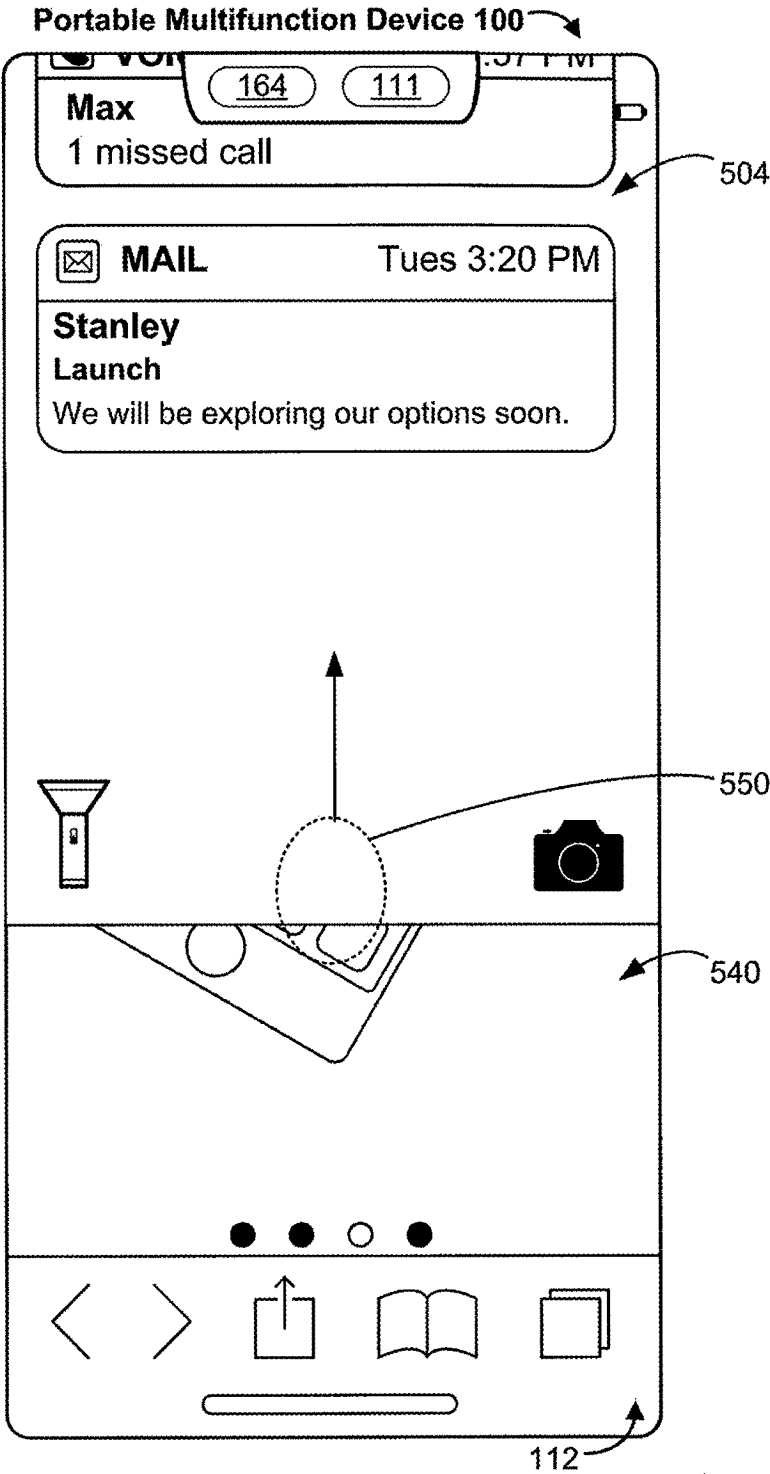


Figure 5AE

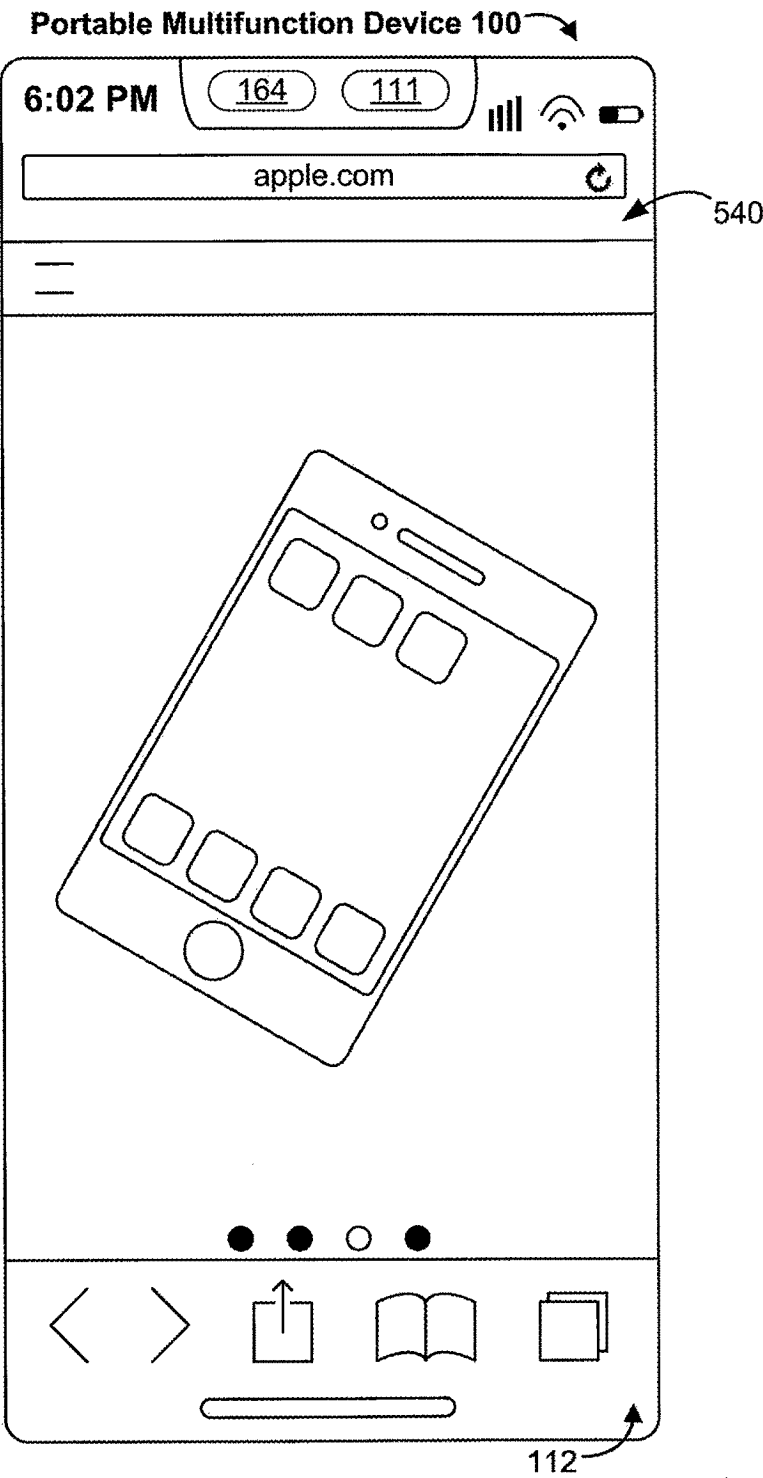


Figure 5AF

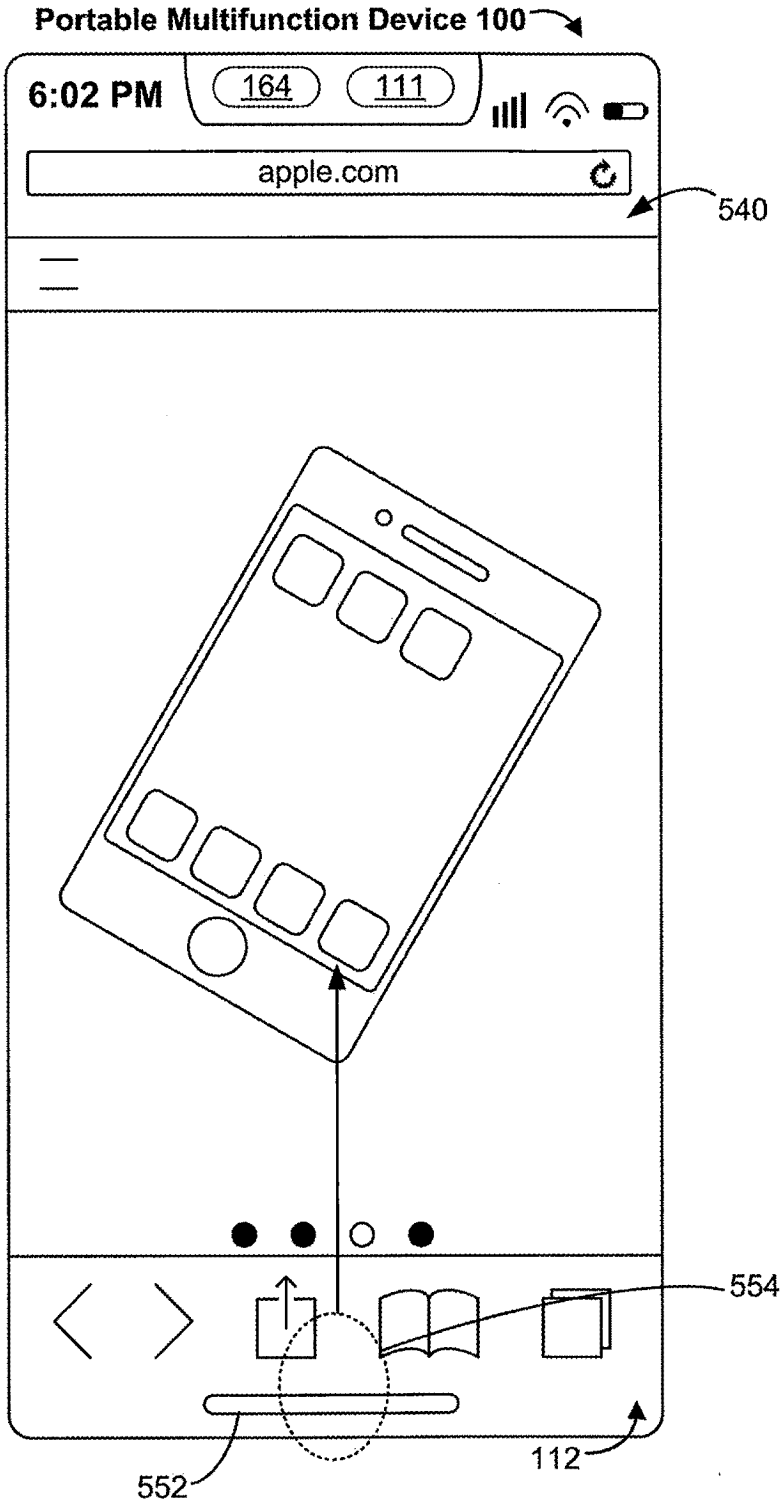


Figure 5AG



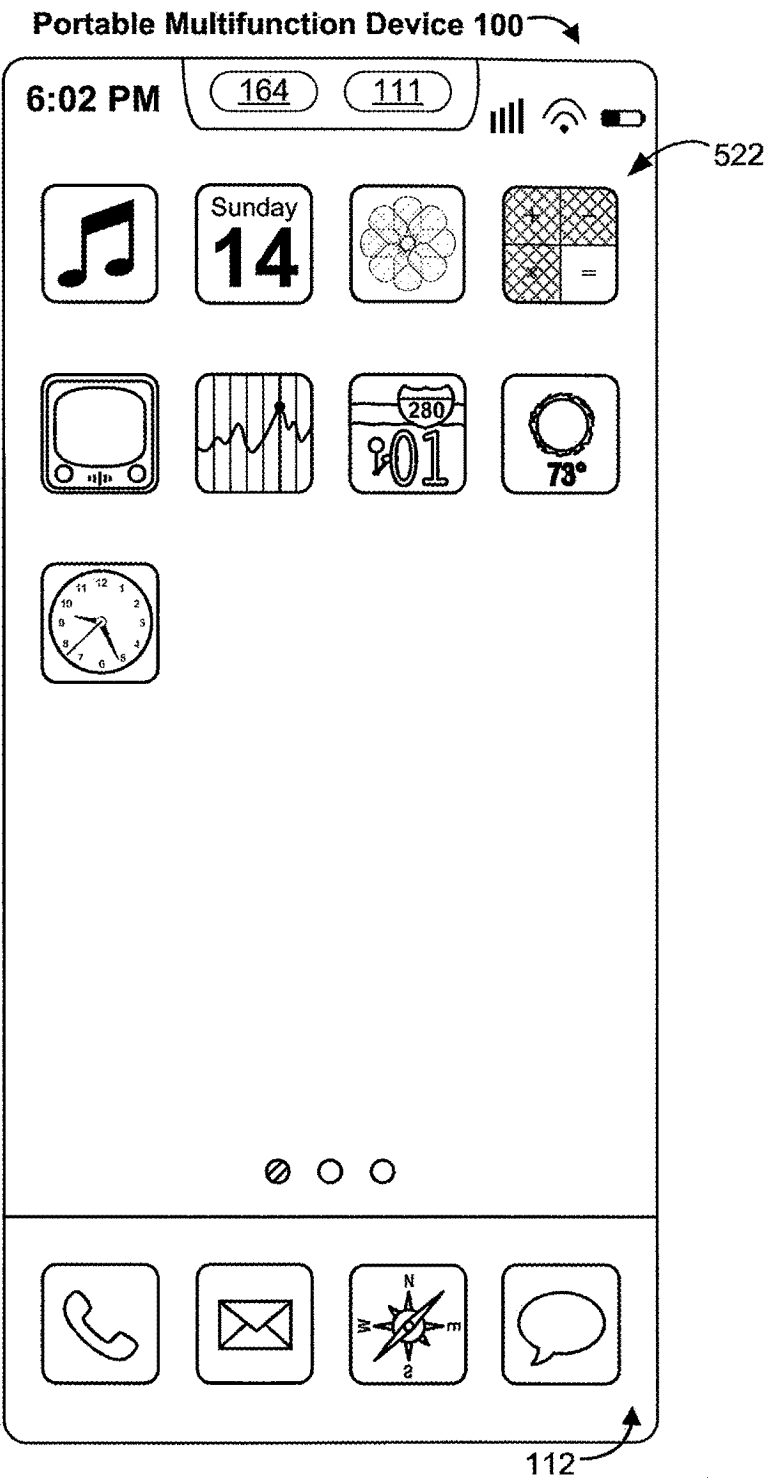


Figure 5AH

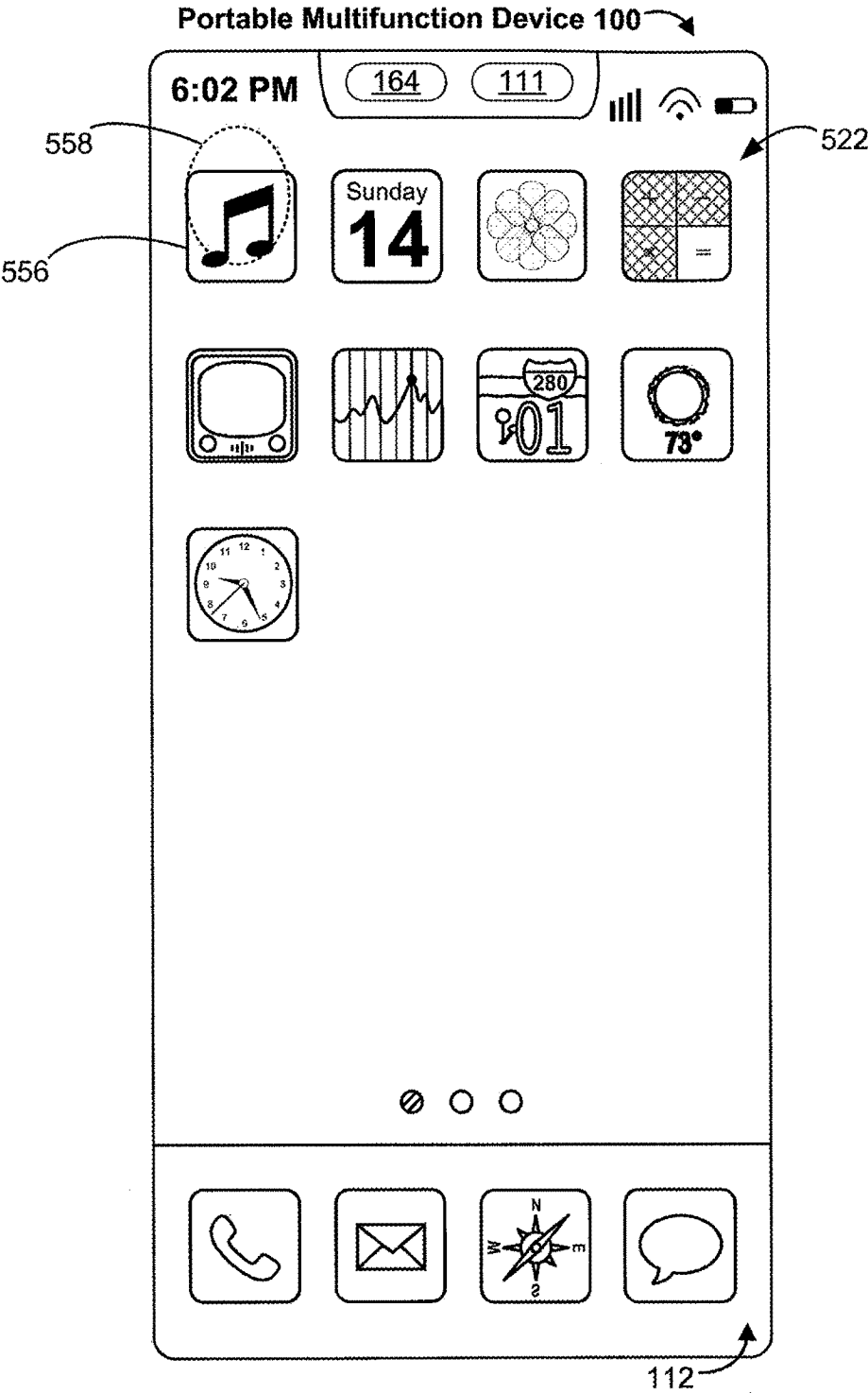


Figure 5A

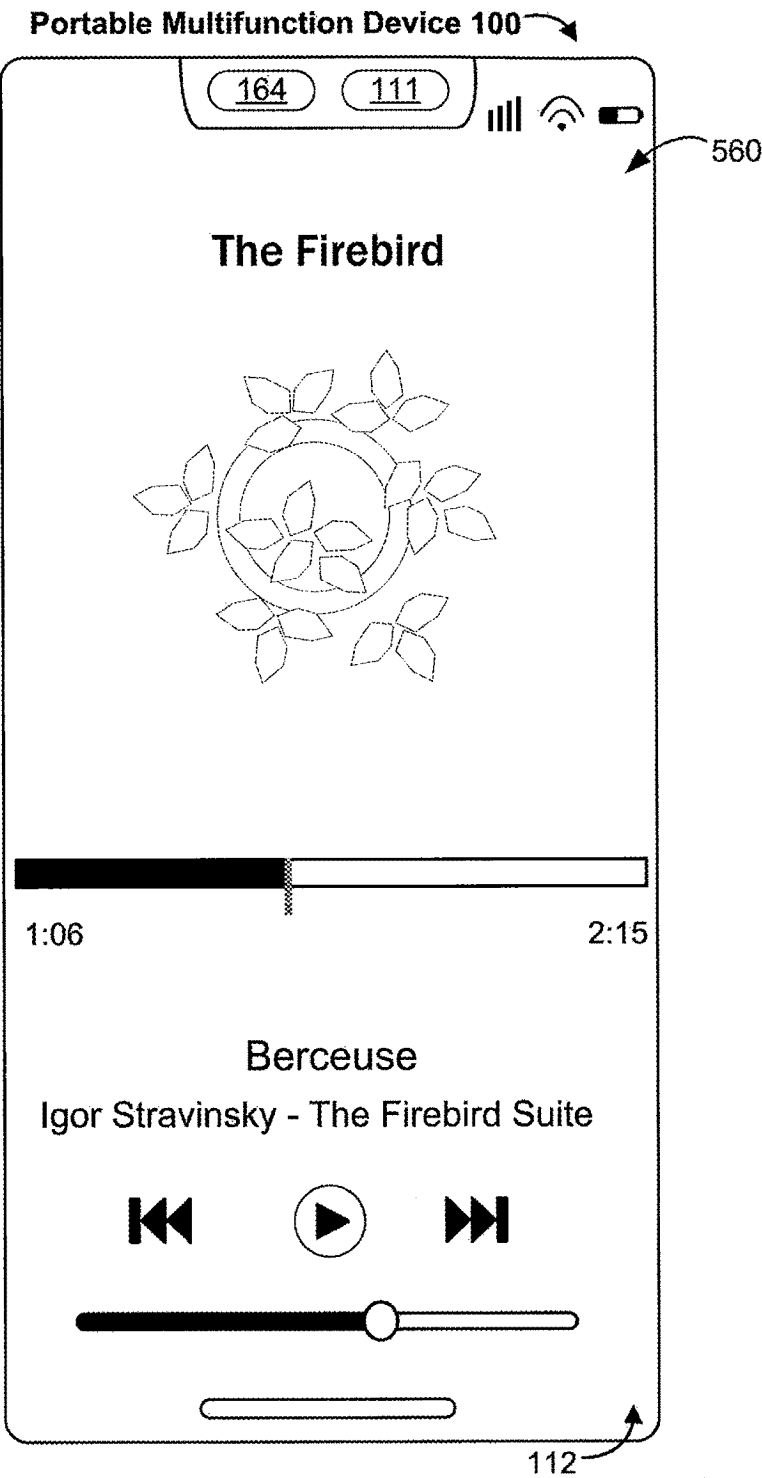


Figure 5AJ

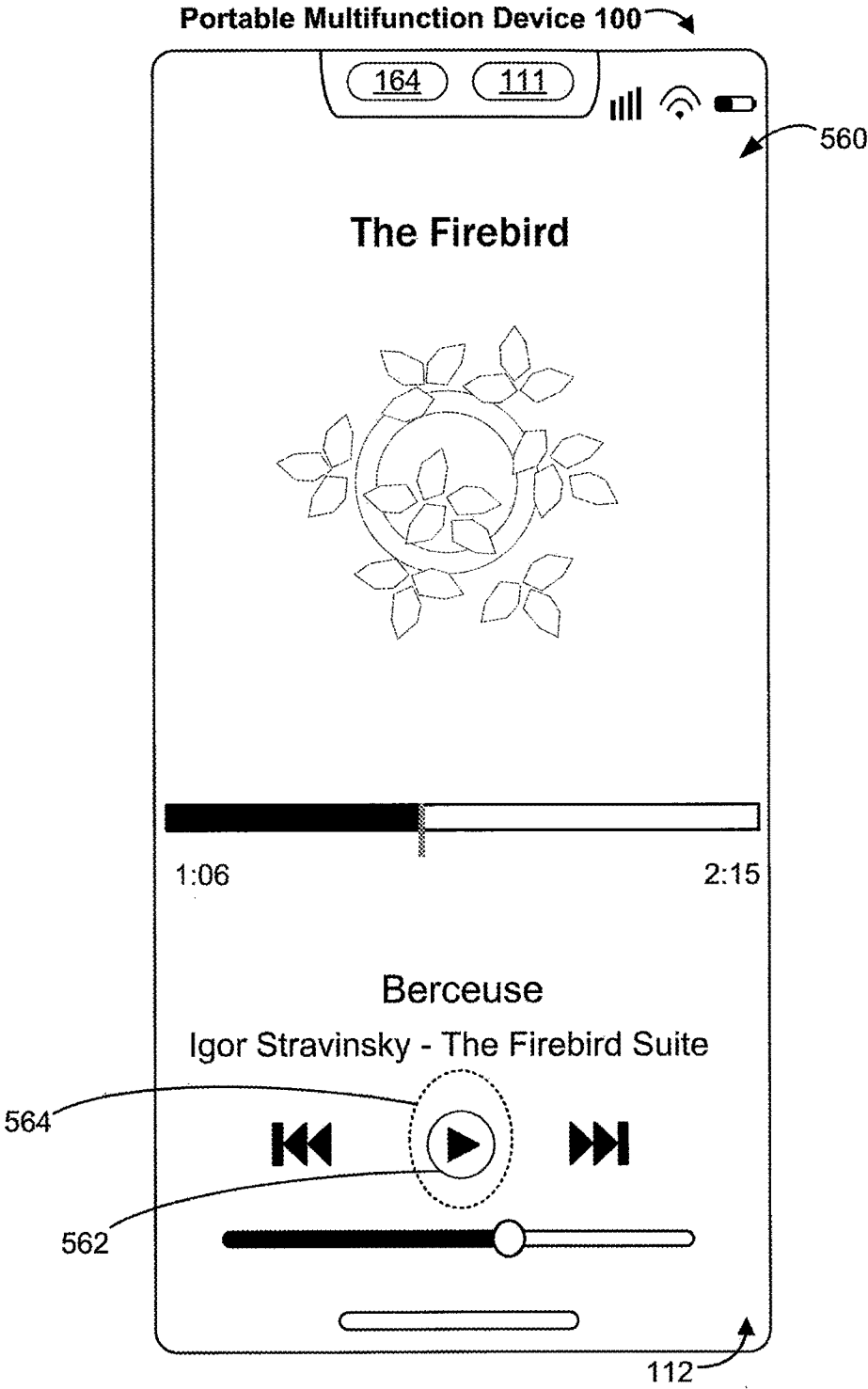


Figure 5AK



Figure 5AL

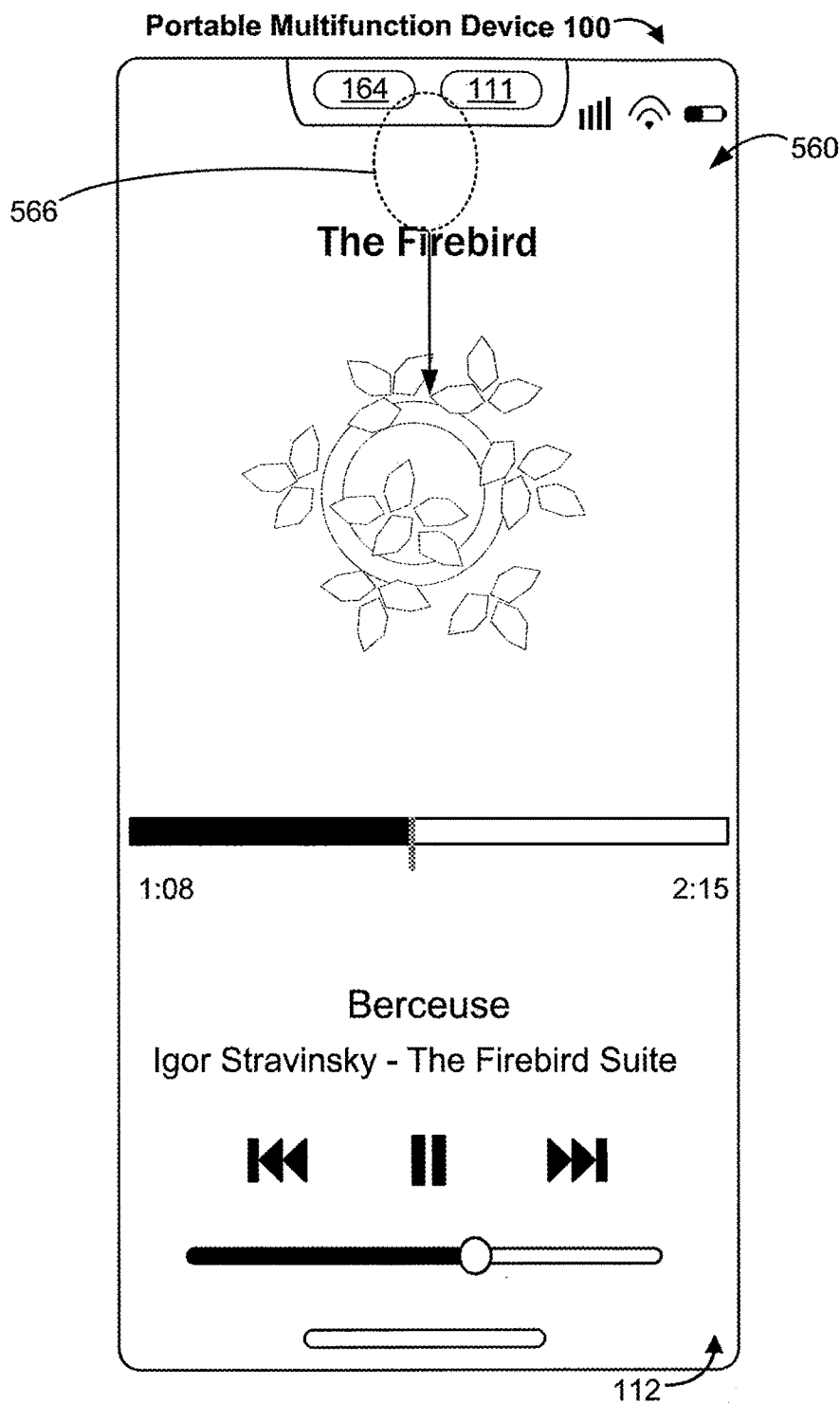


Figure 5AM



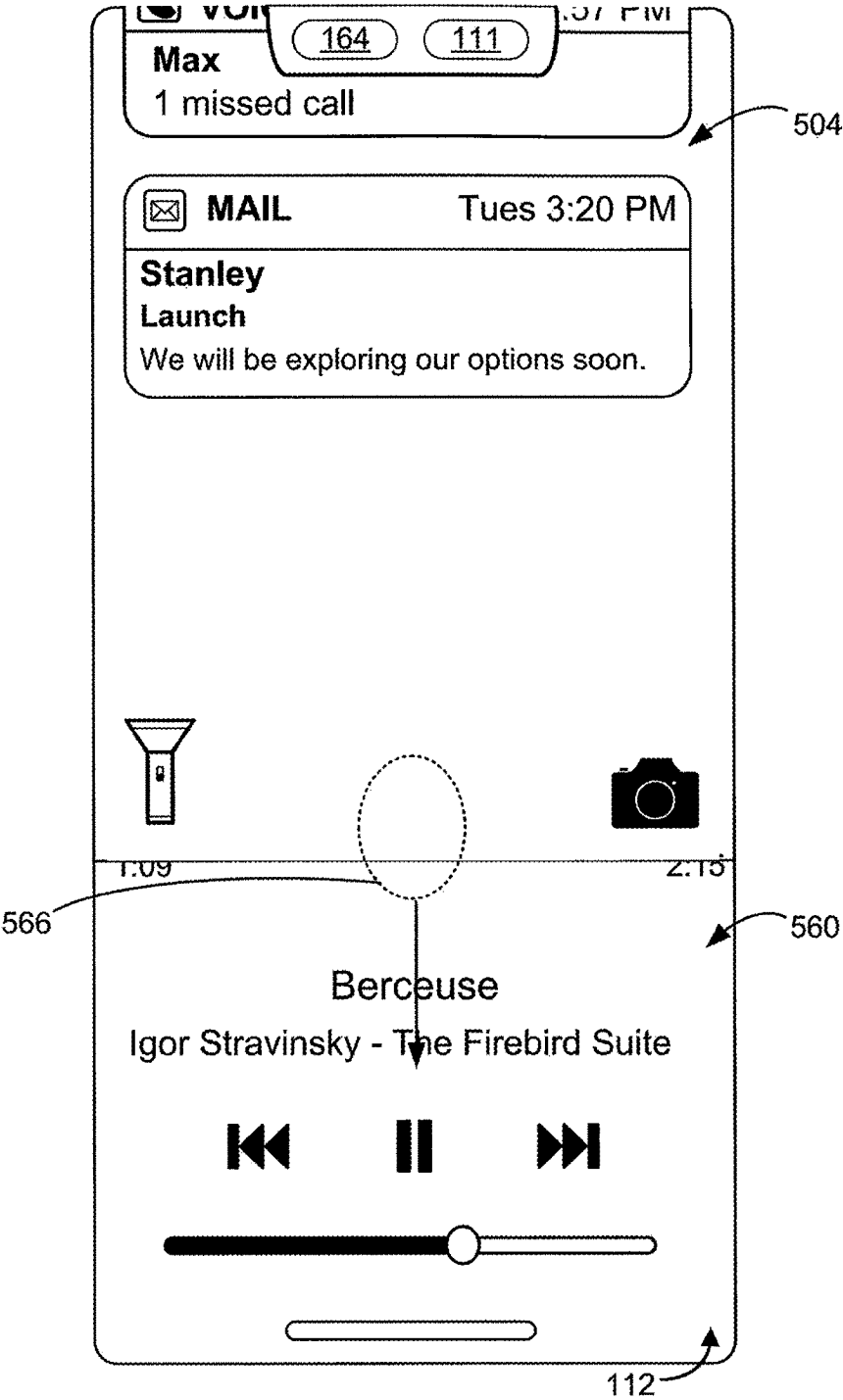


Figure 5AN

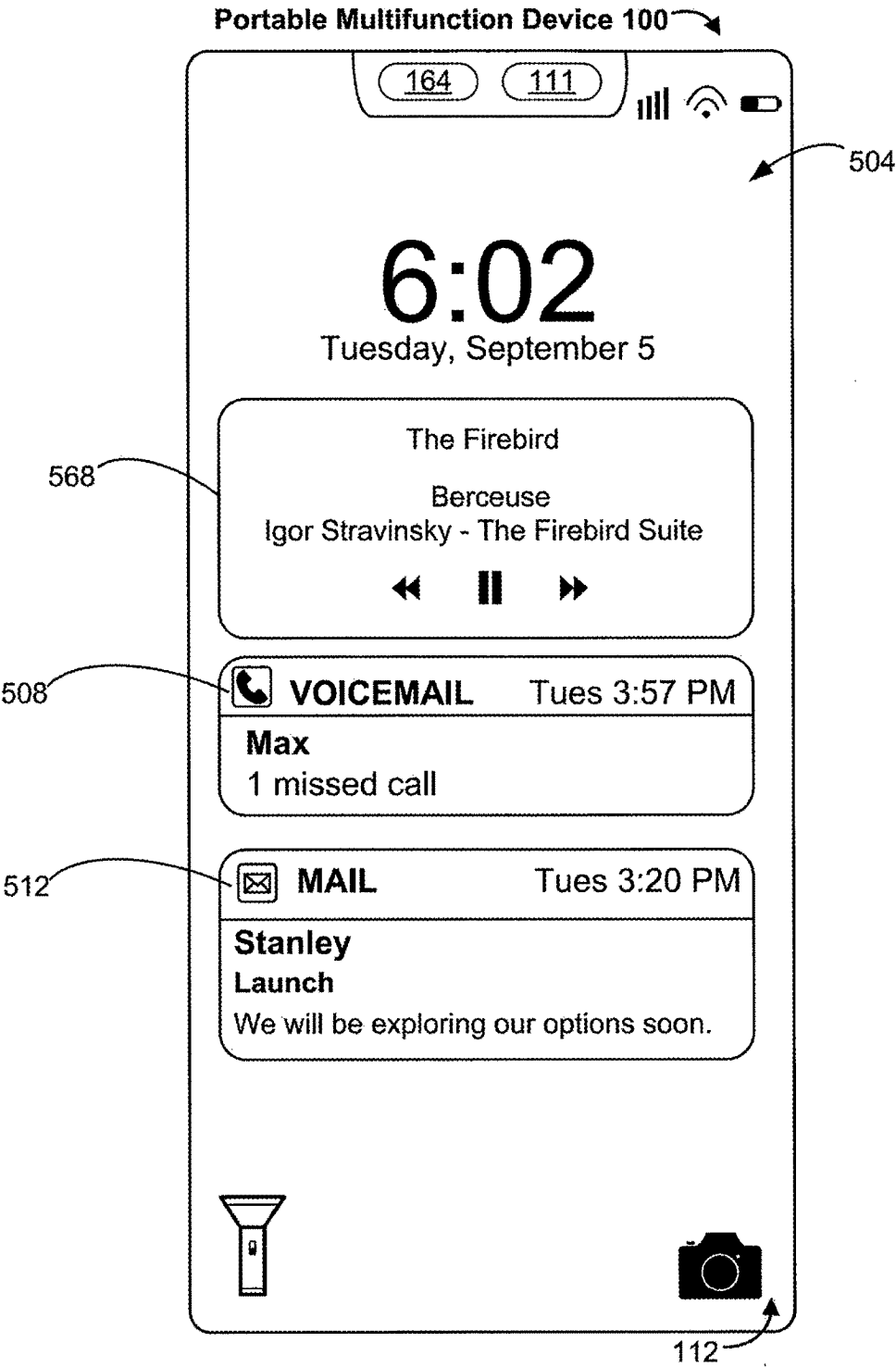


Figure 5AO

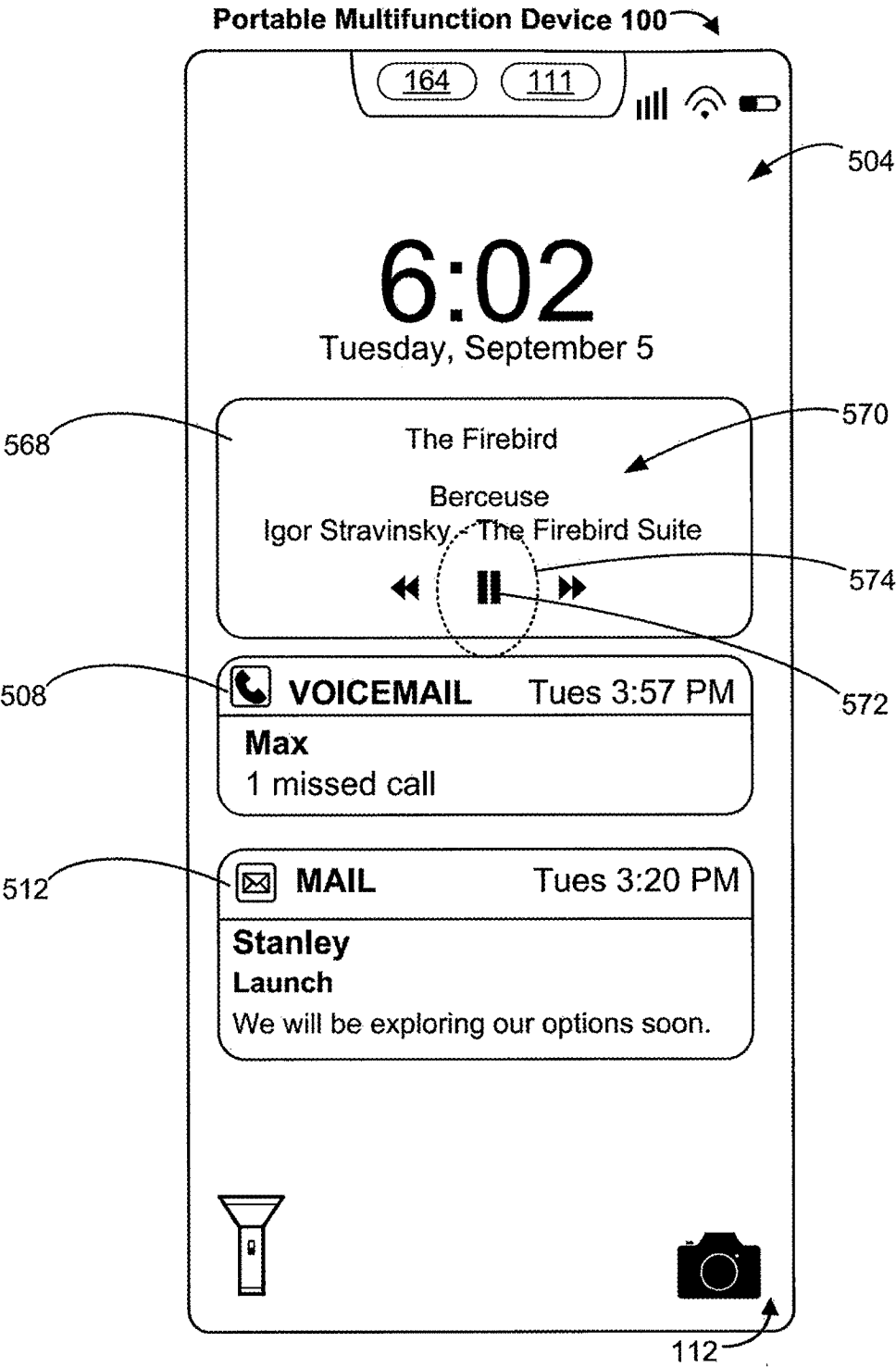


Figure 5AP

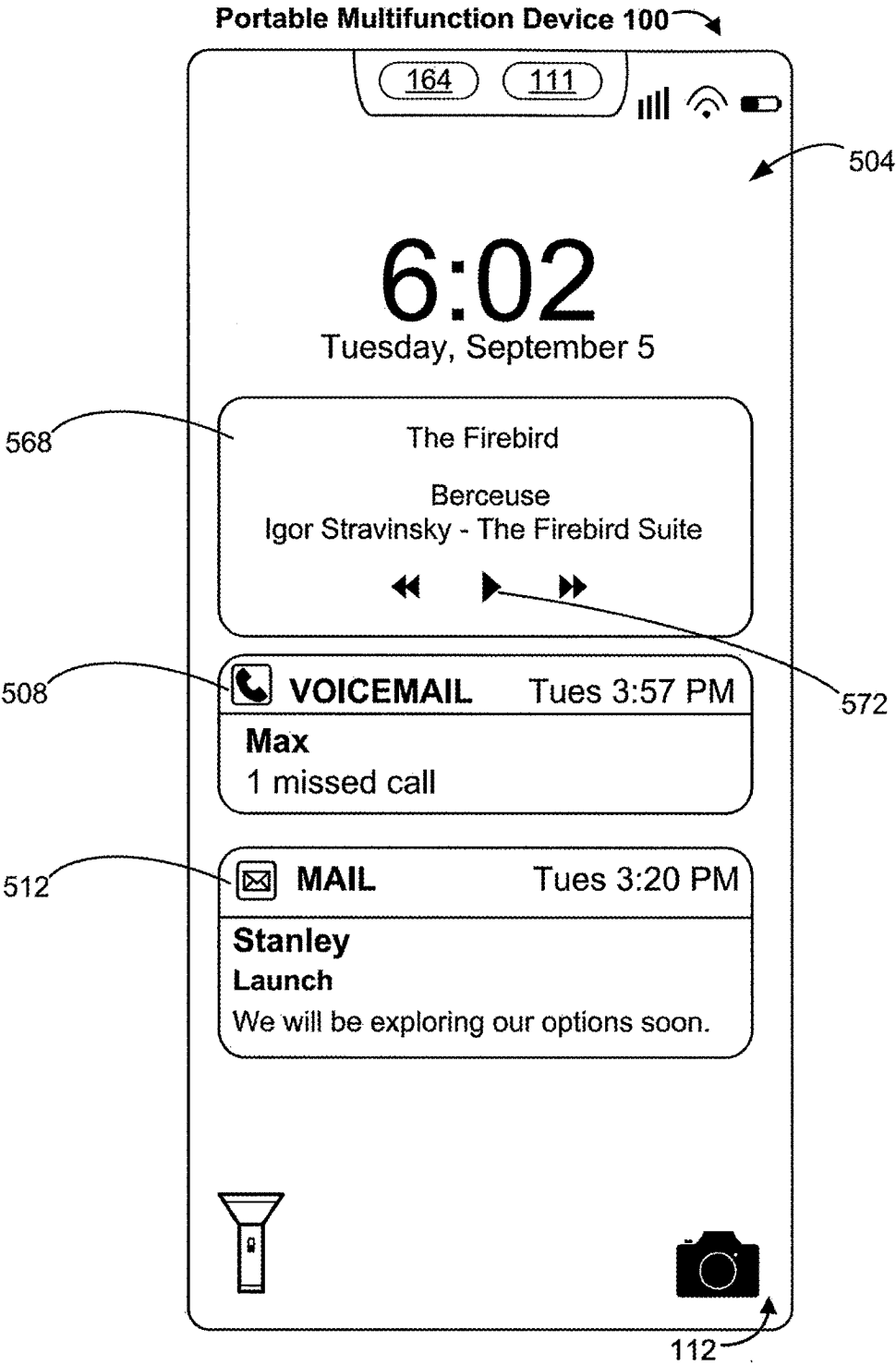


Figure 5AQ

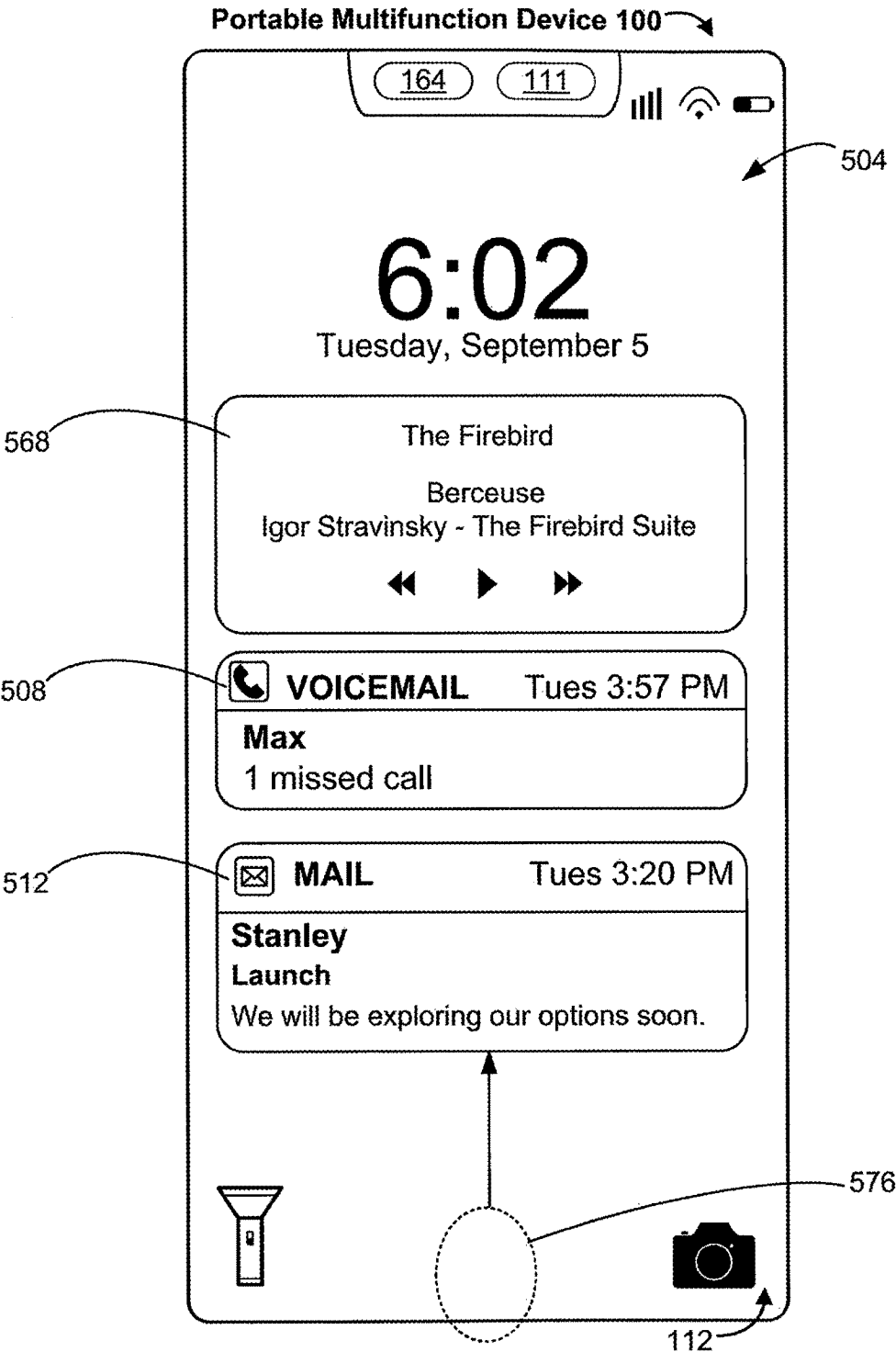


Figure 5AR

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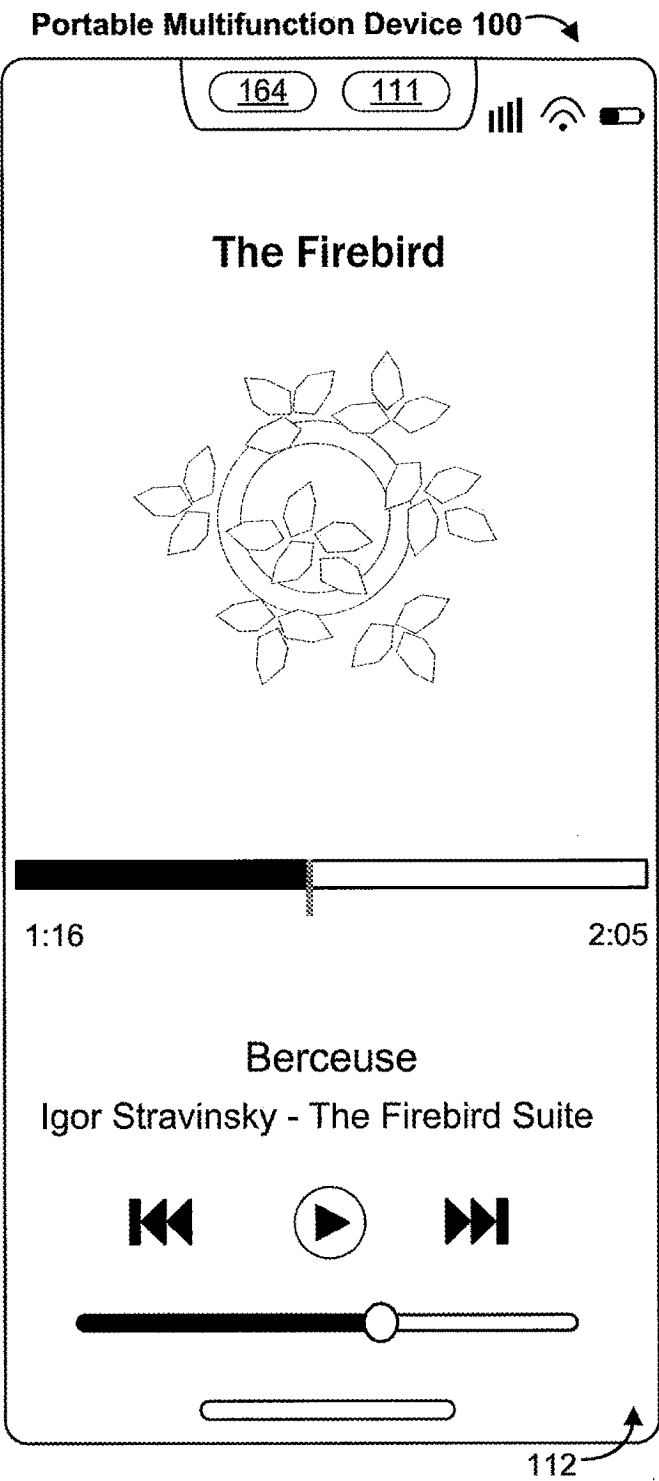


Figure 5AS



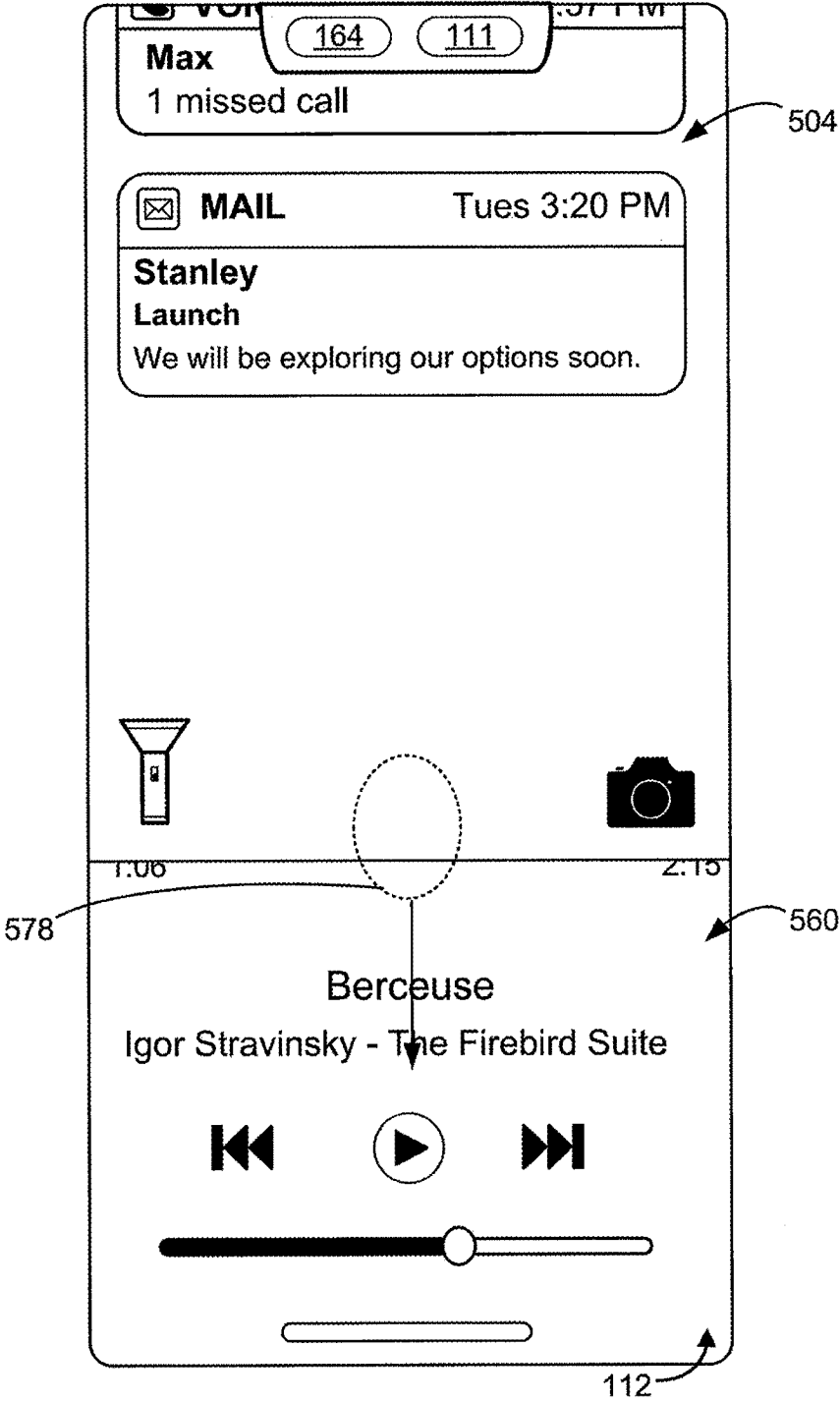


Figure 5AT

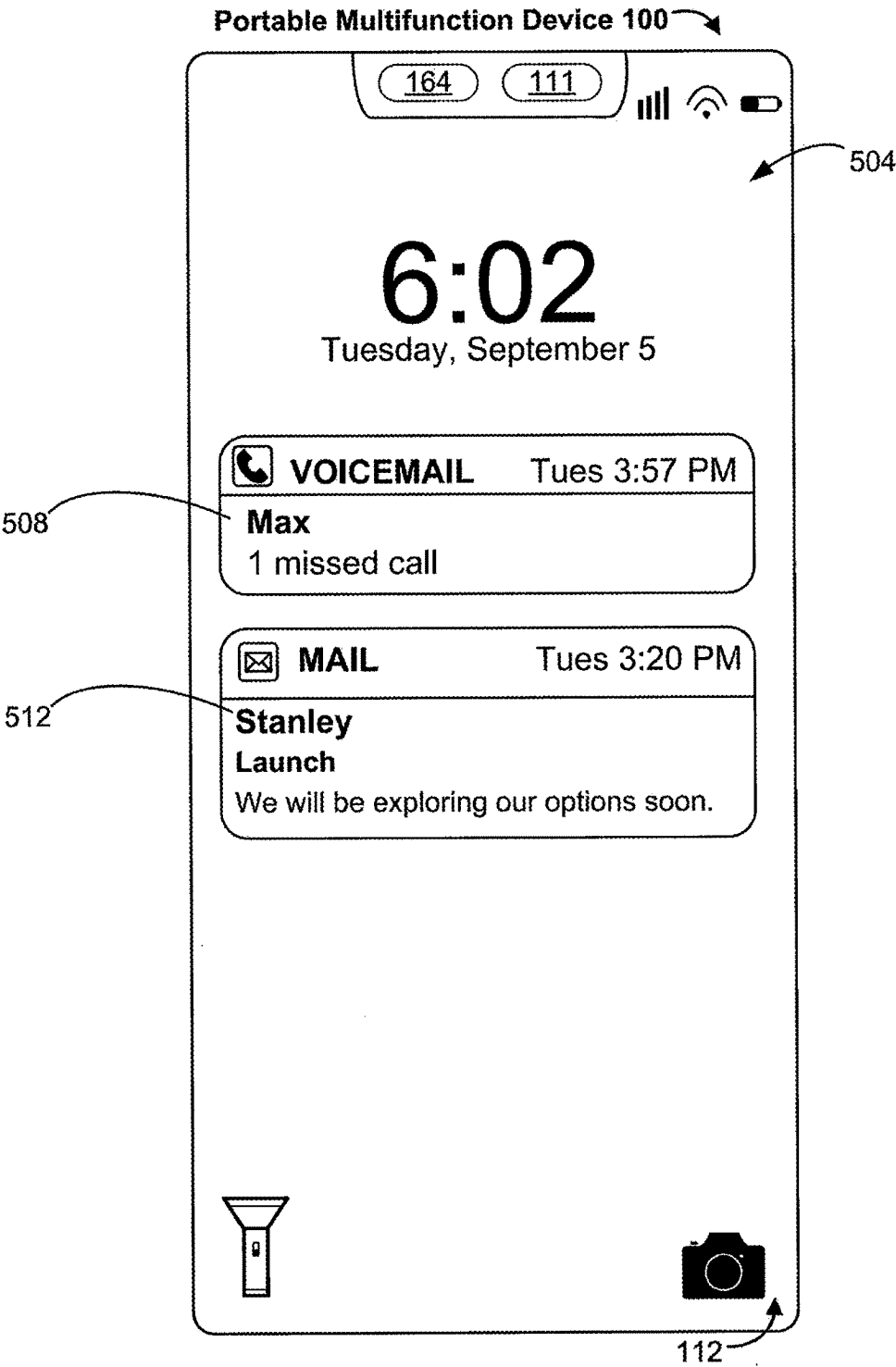


Figure 5AU

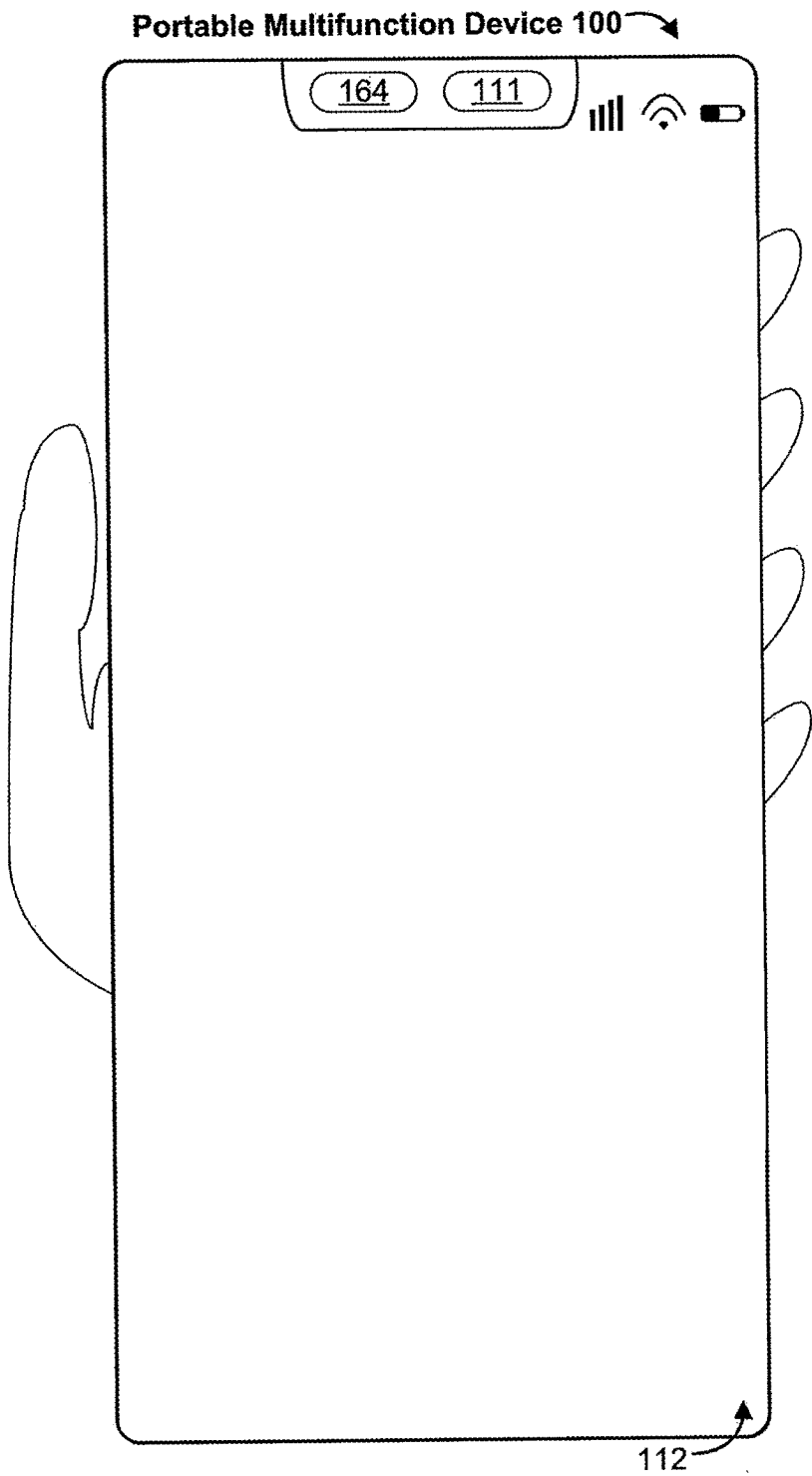


Figure 5AV

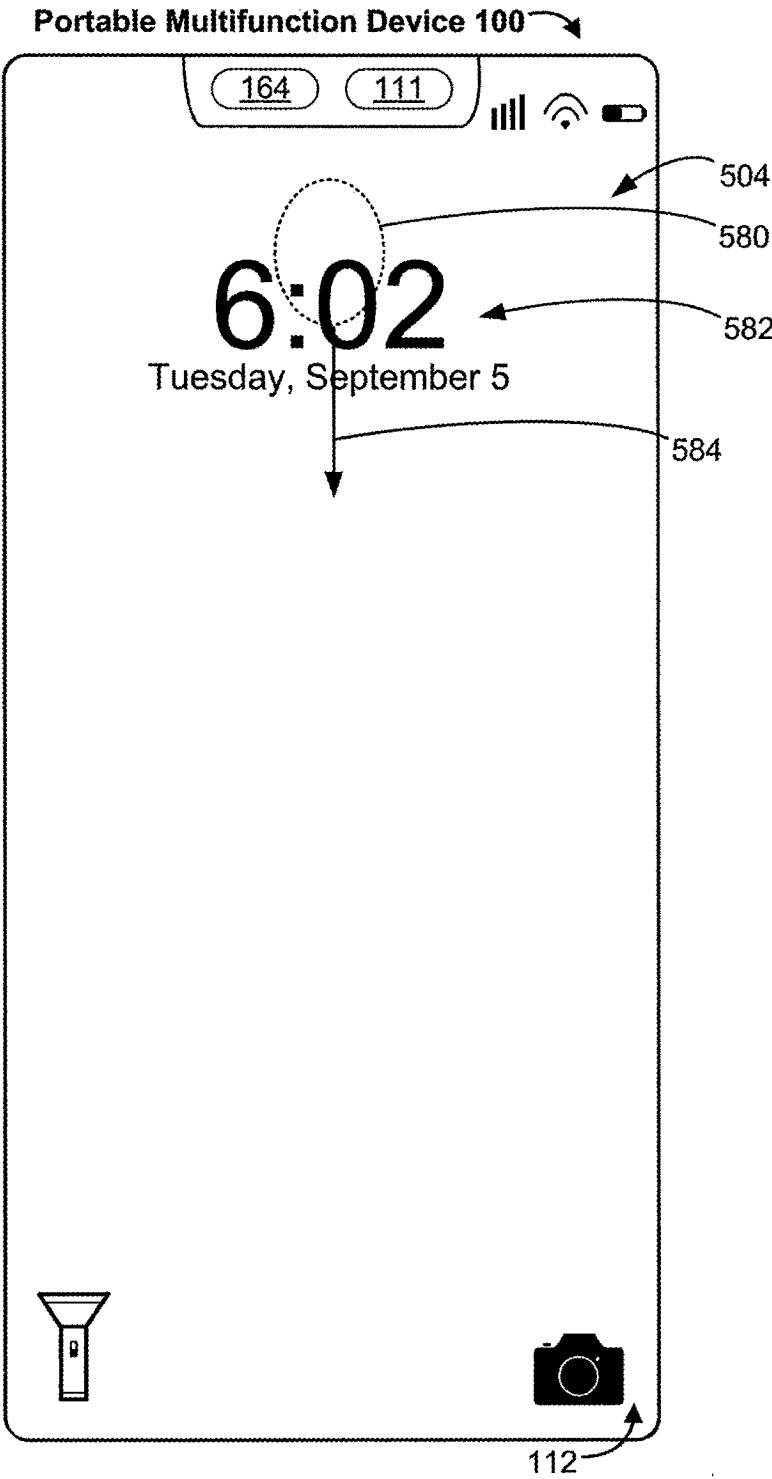


Figure 5AW

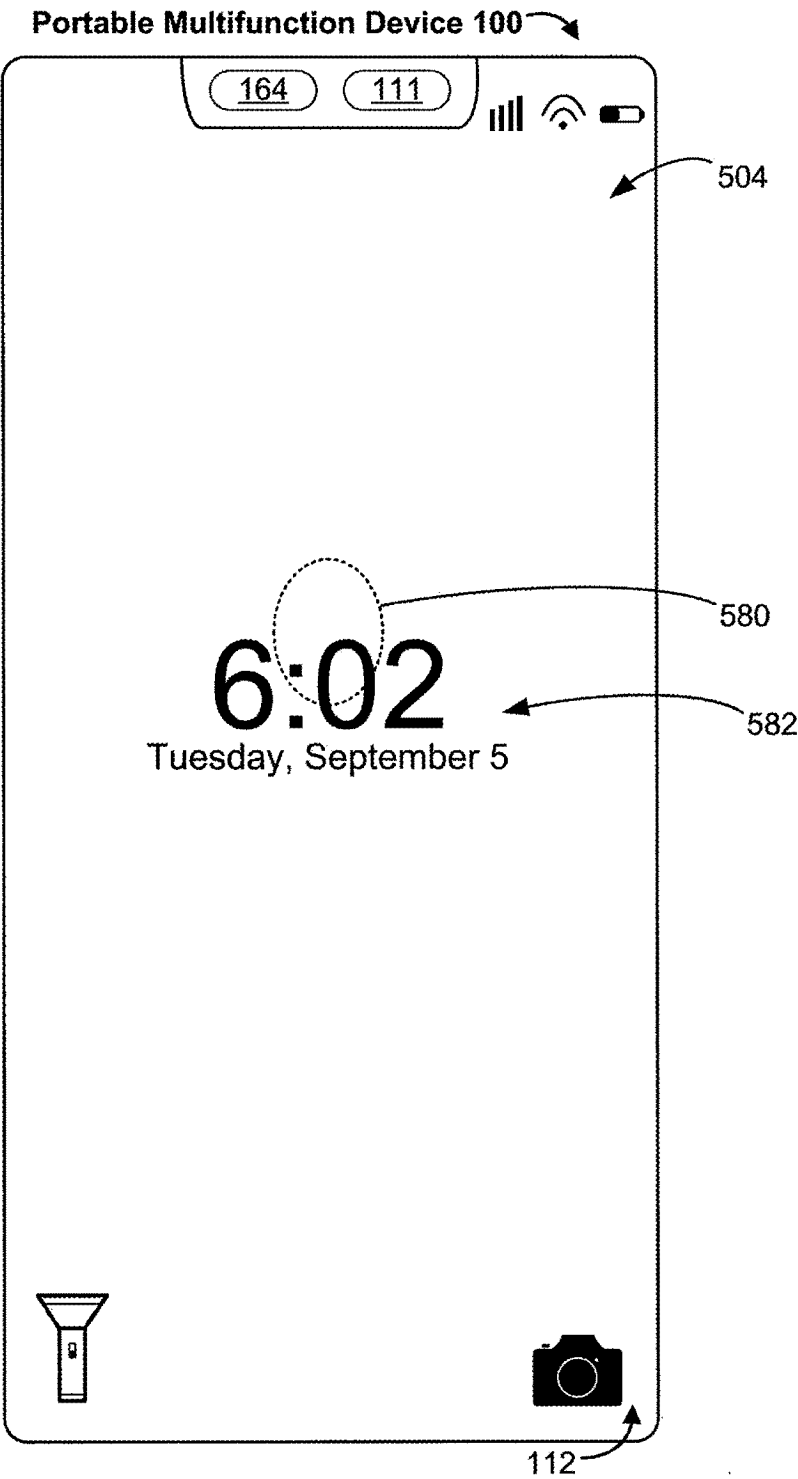


Figure 5AX

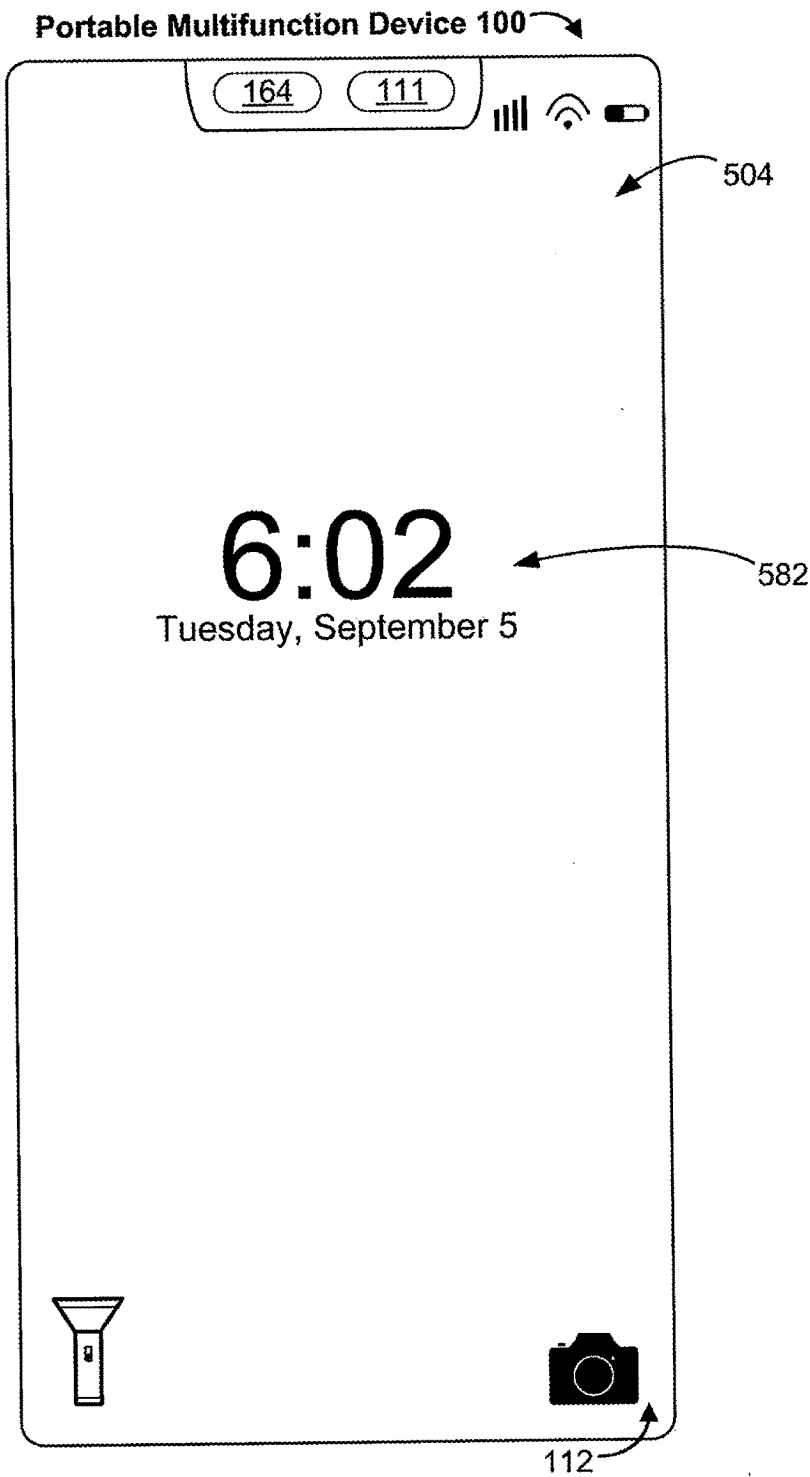


Figure 5AY



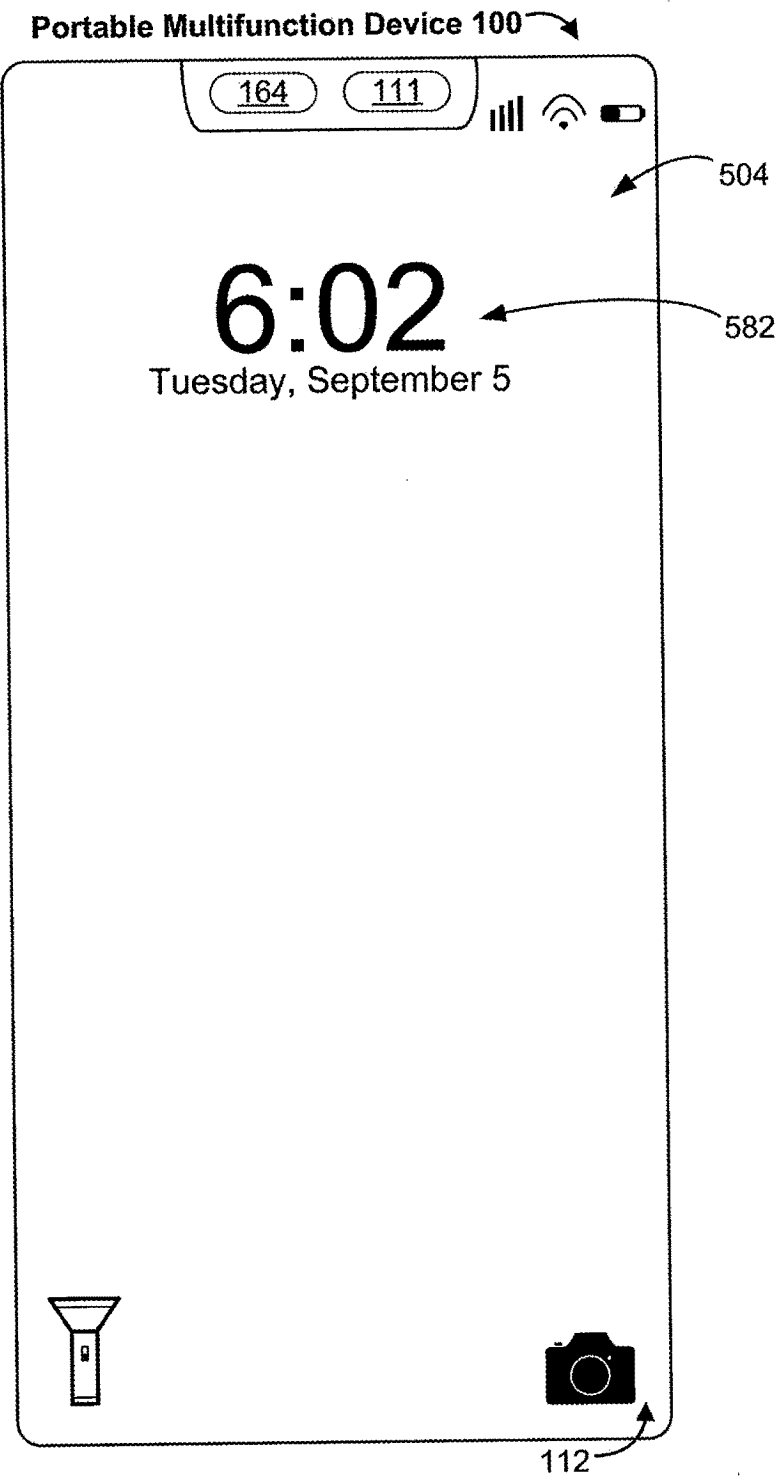


Figure 5AZ

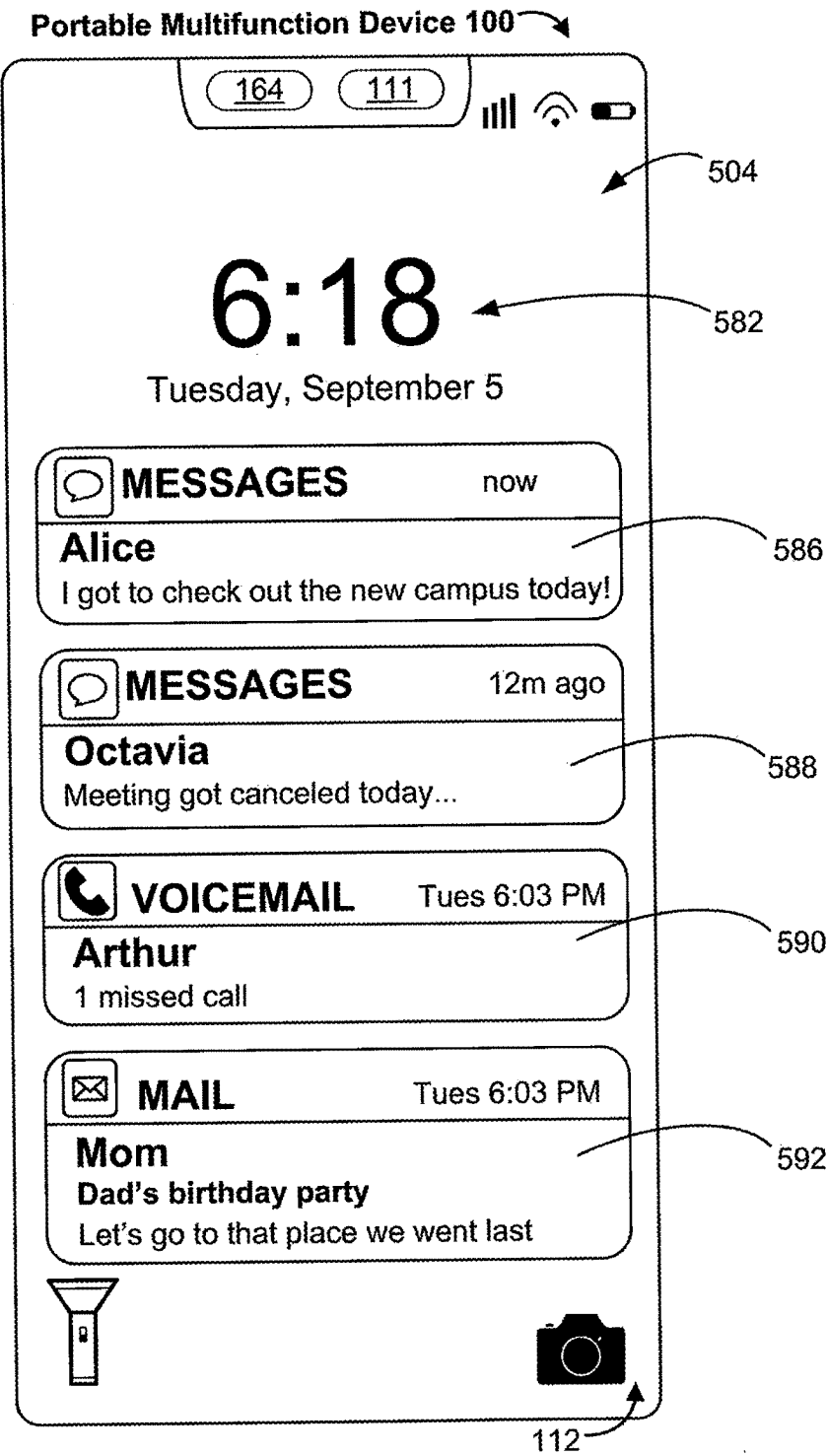


Figure 5BA

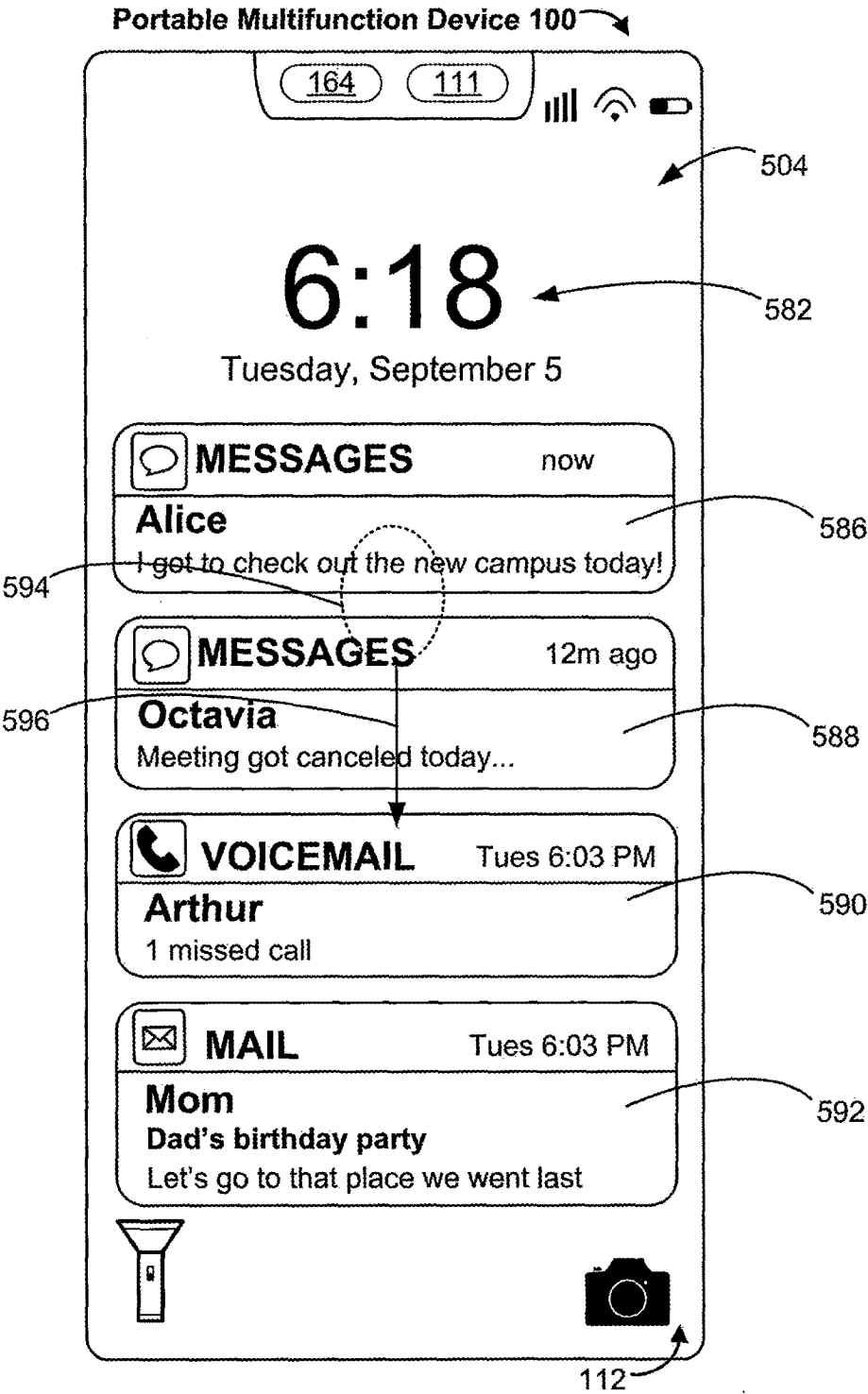


Figure 5BB

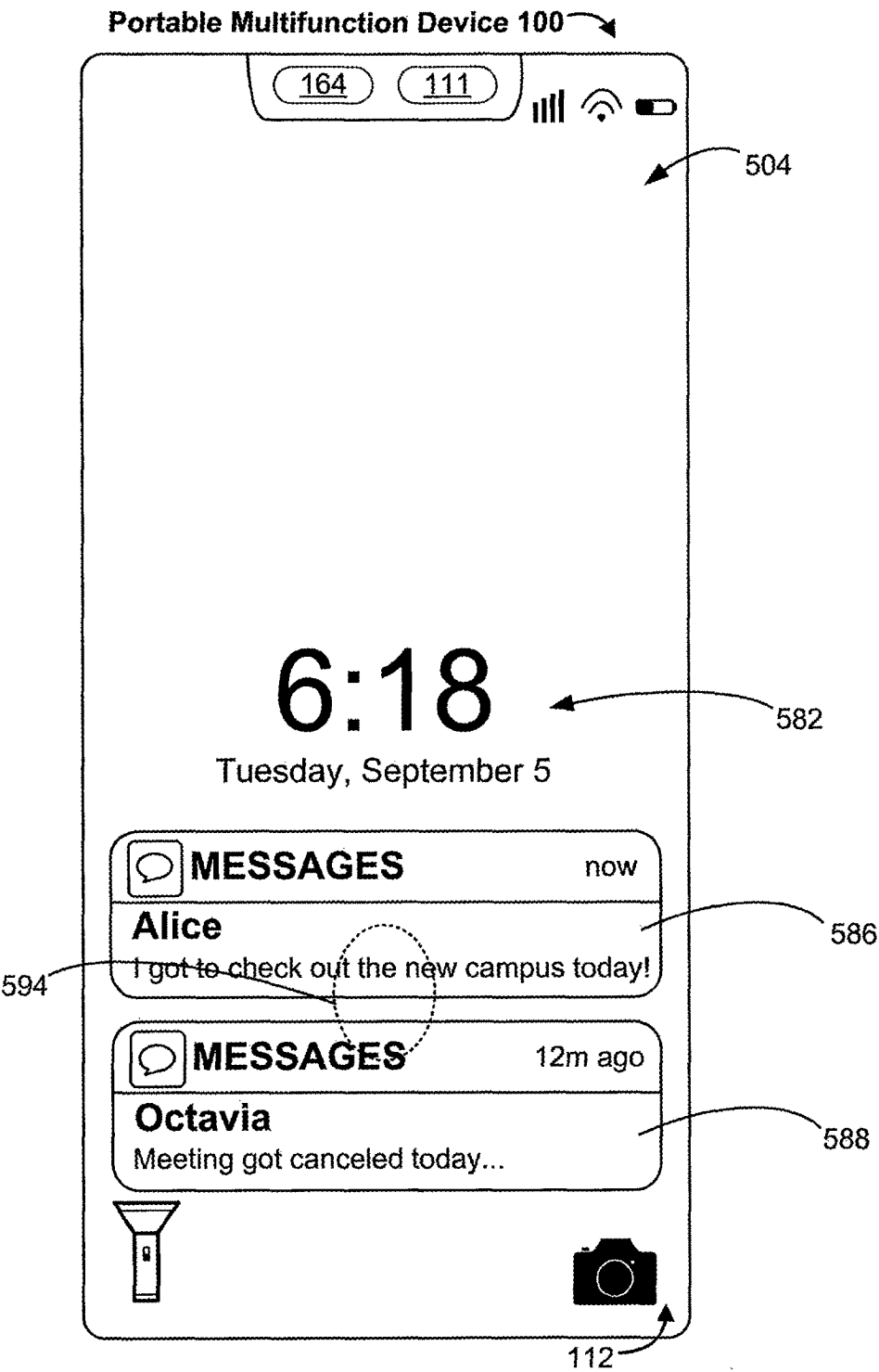


Figure 5BC

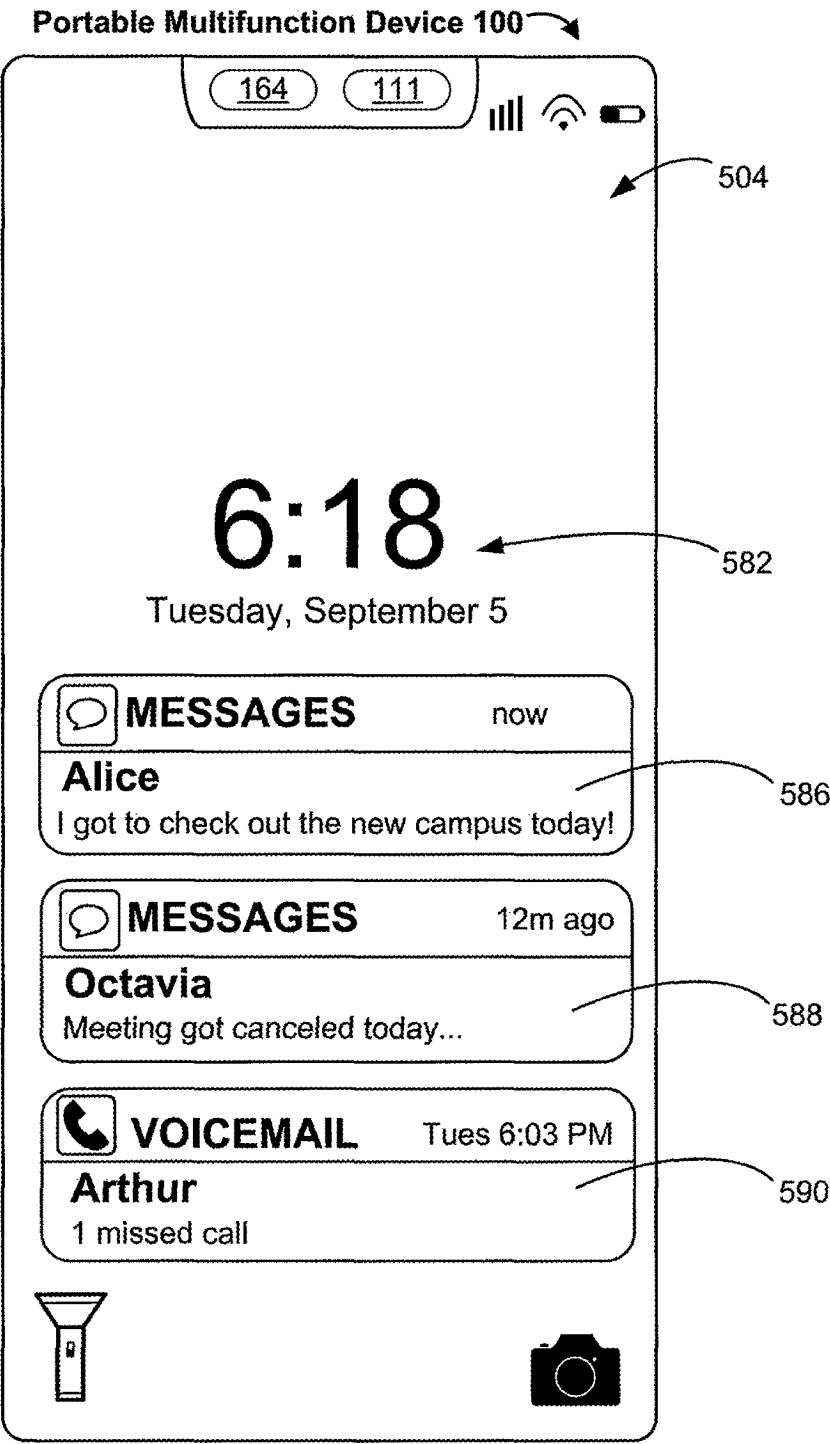


Figure 5BD

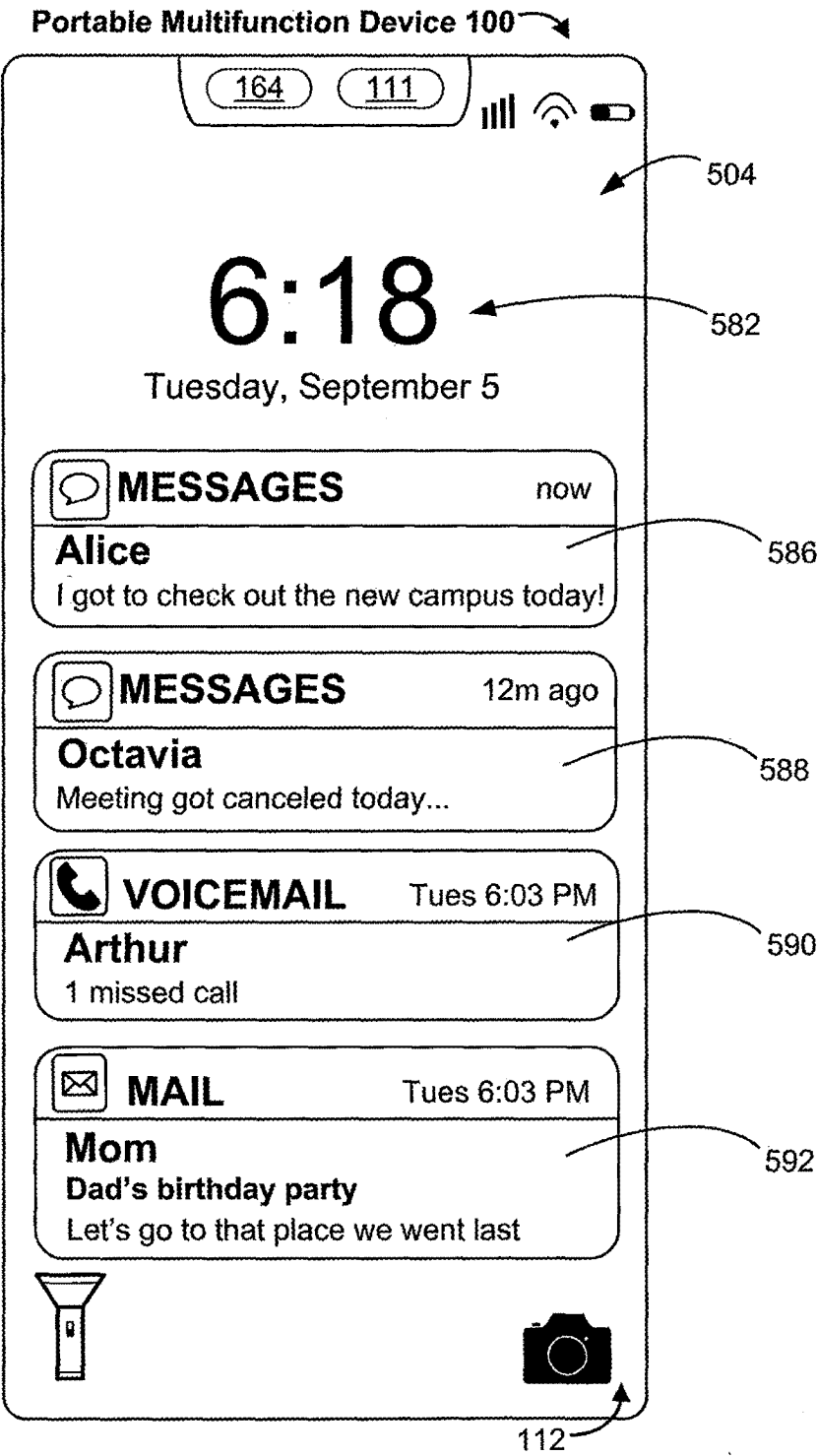


Figure 5BE



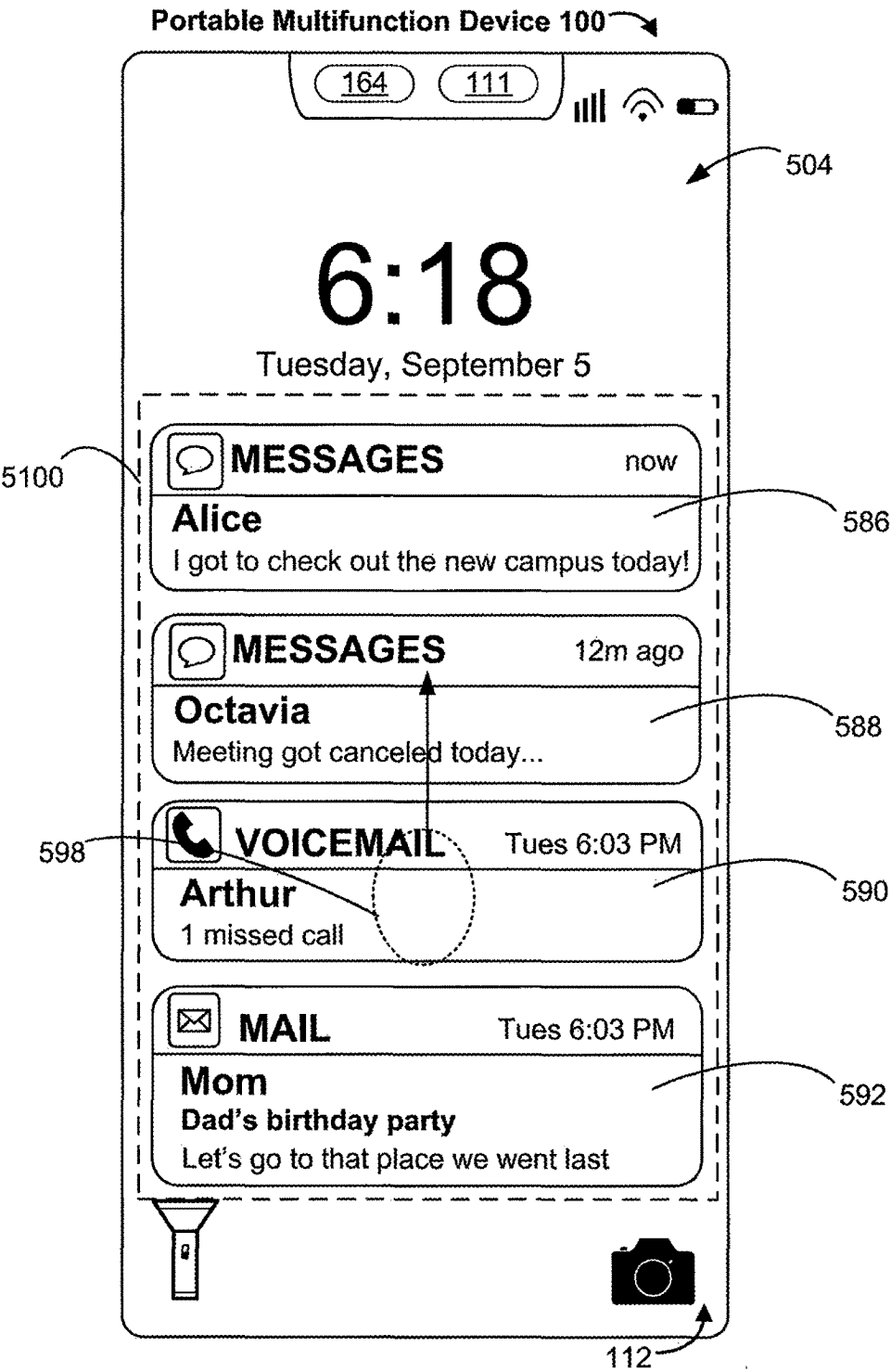


Figure 5BF

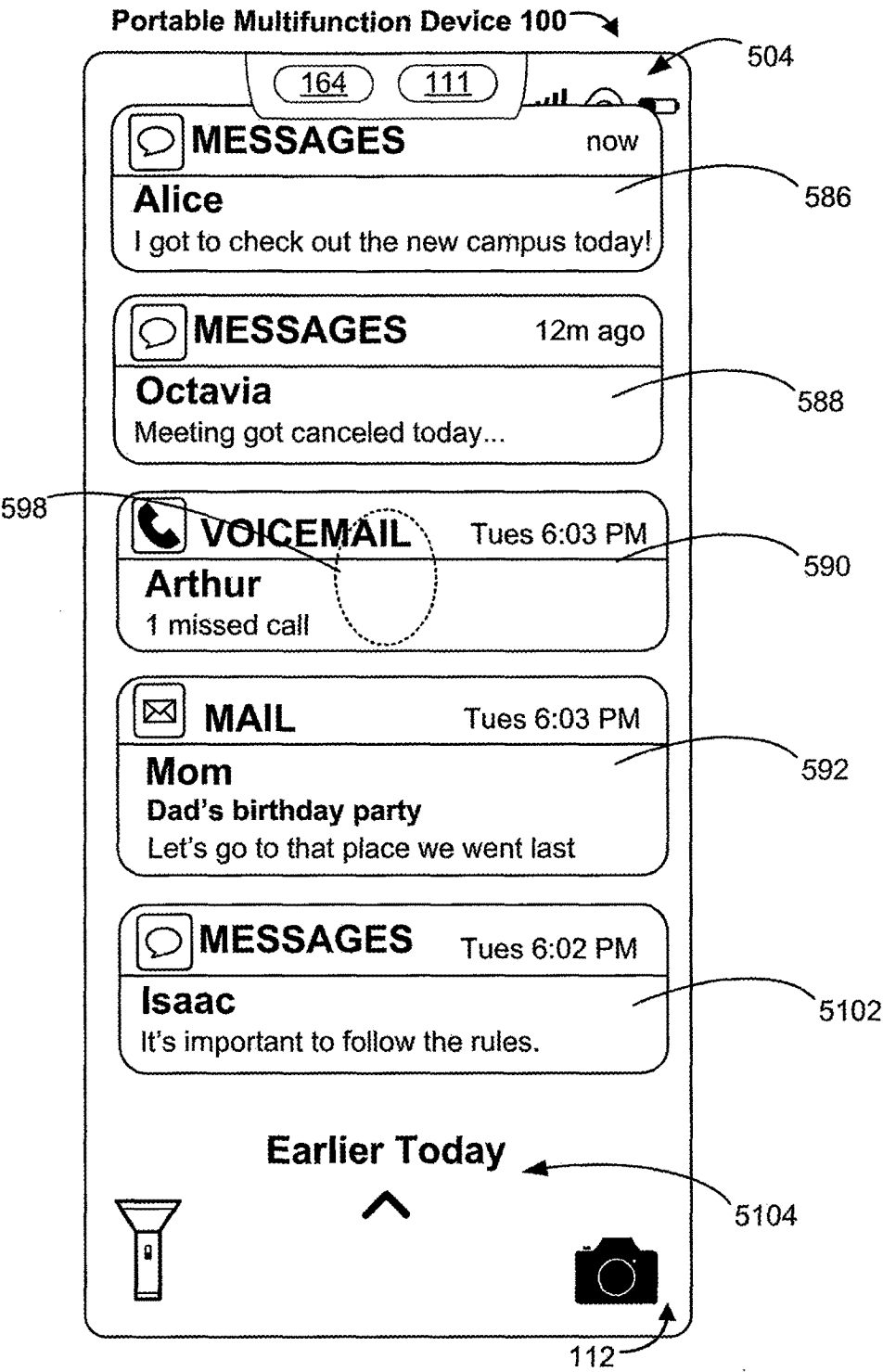


Figure 5BG

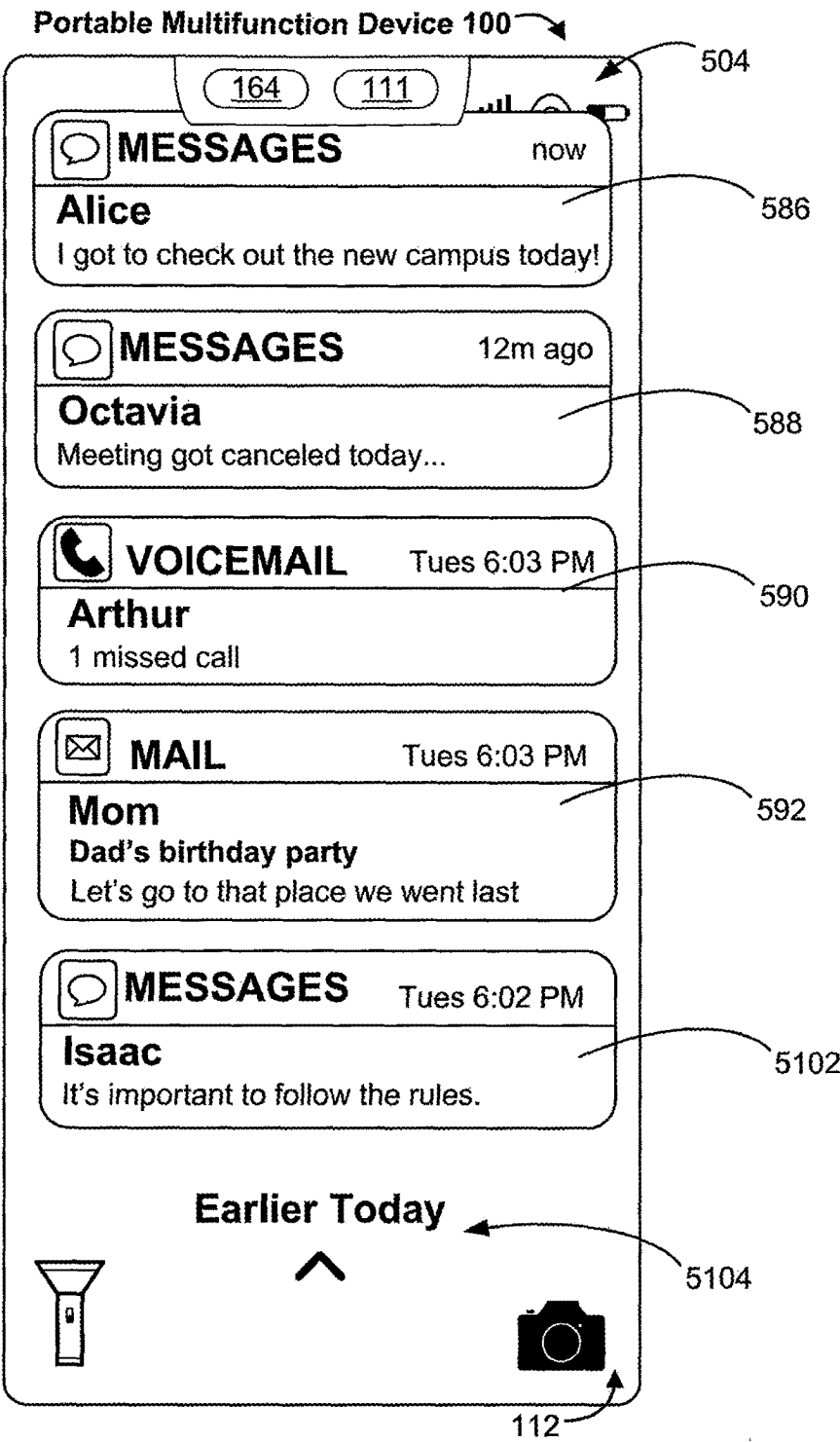


Figure 5BH

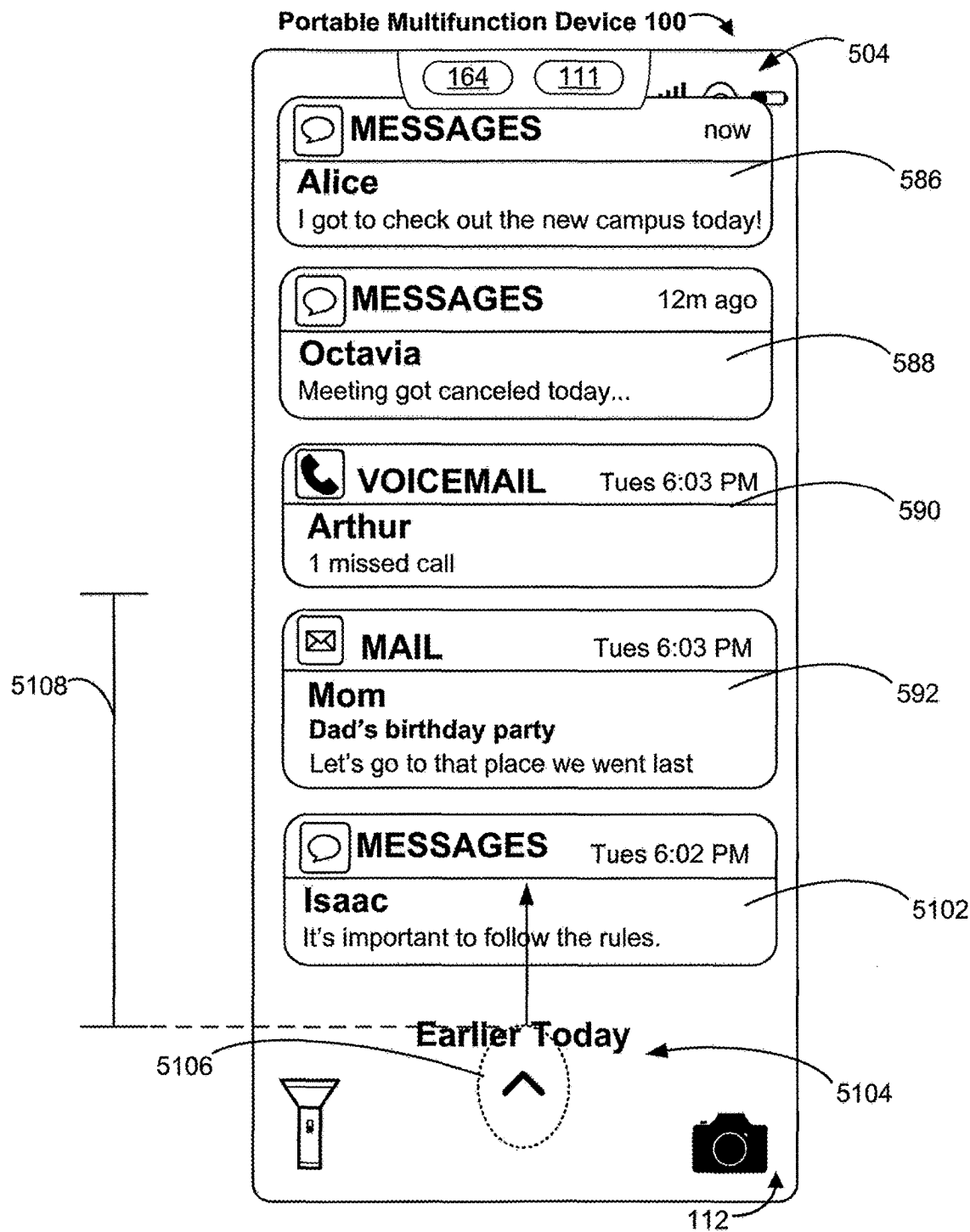


Figure 5BI

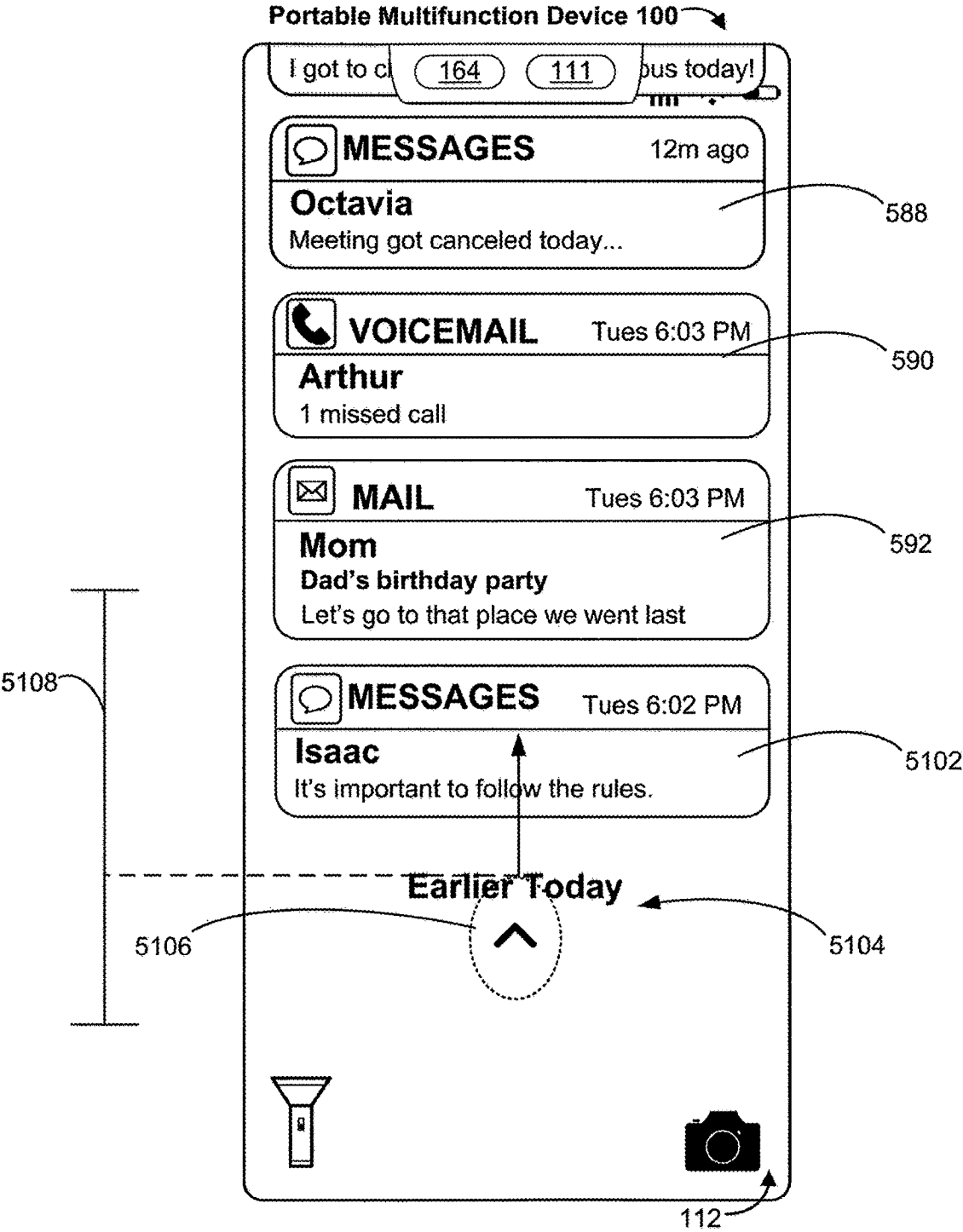


Figure 5BJ

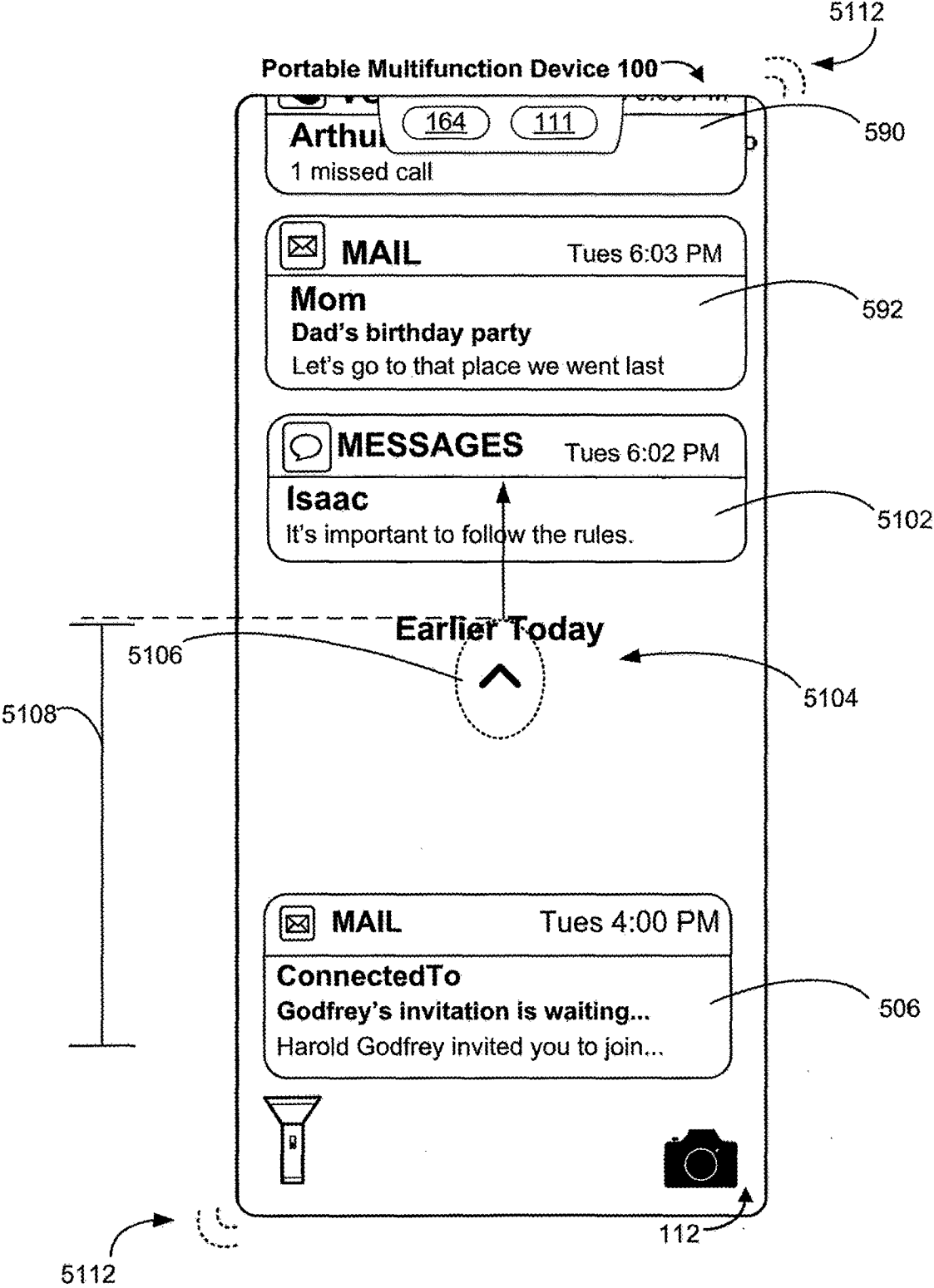


Figure 5BK



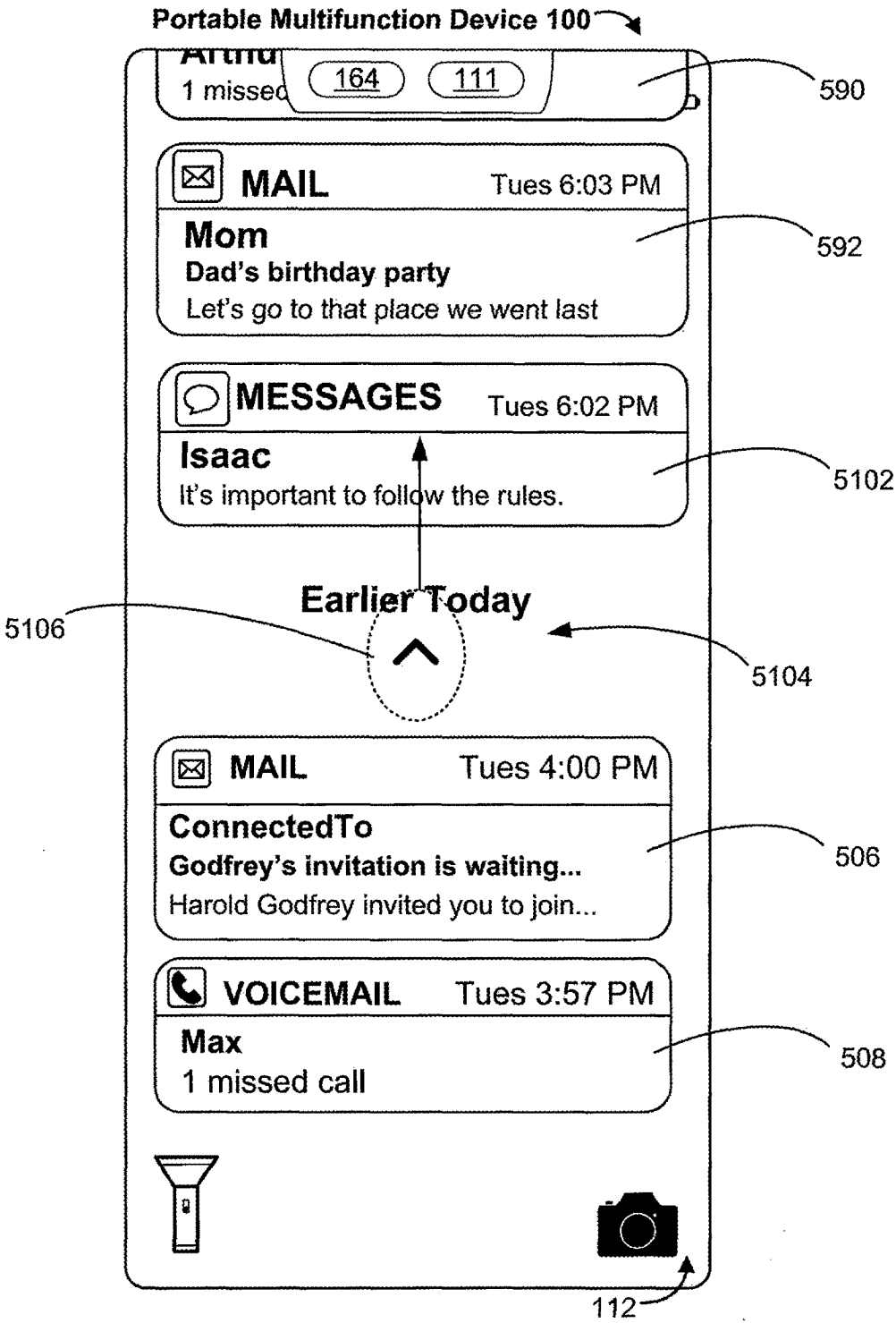


Figure 5BL

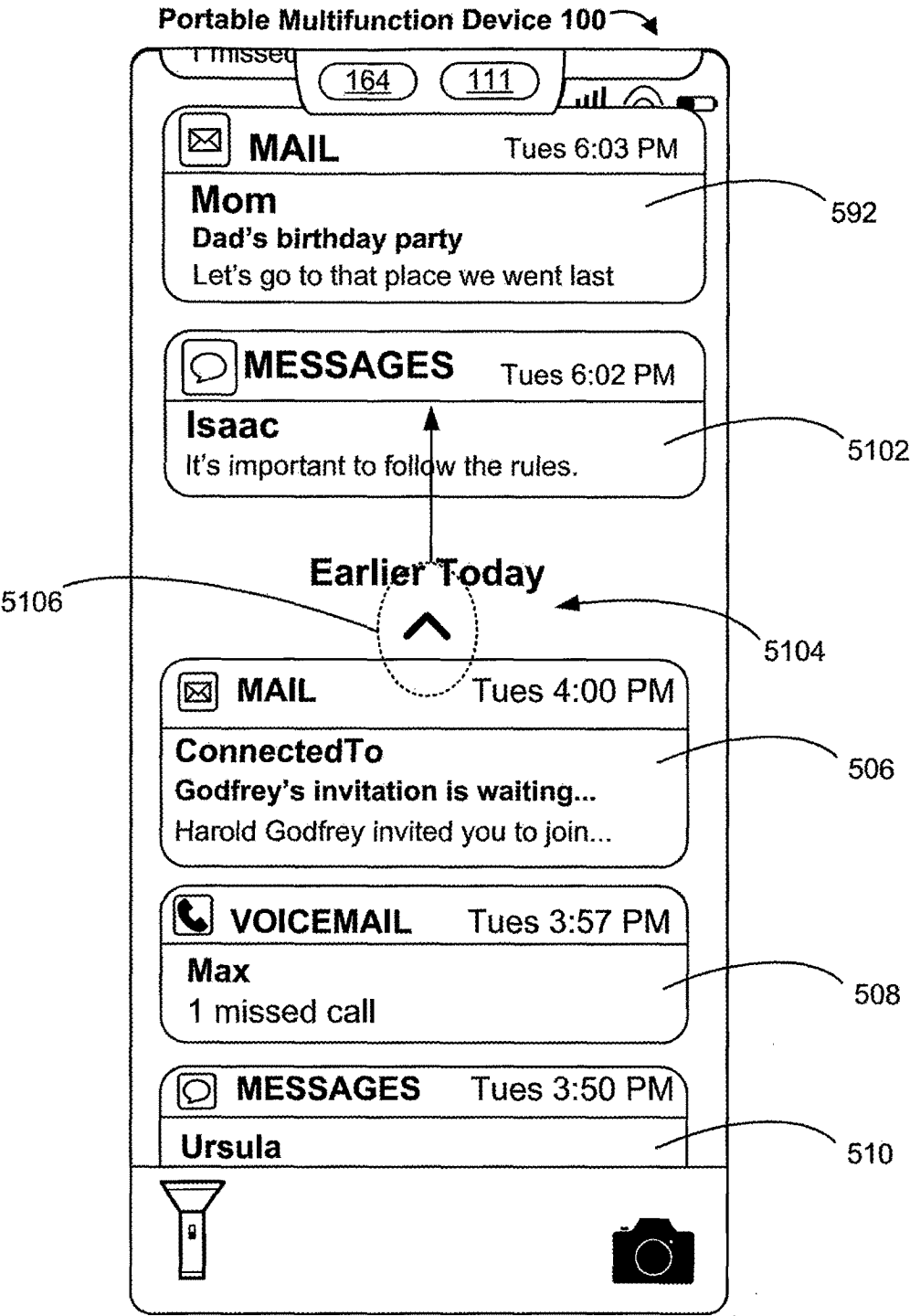


Figure 5BM

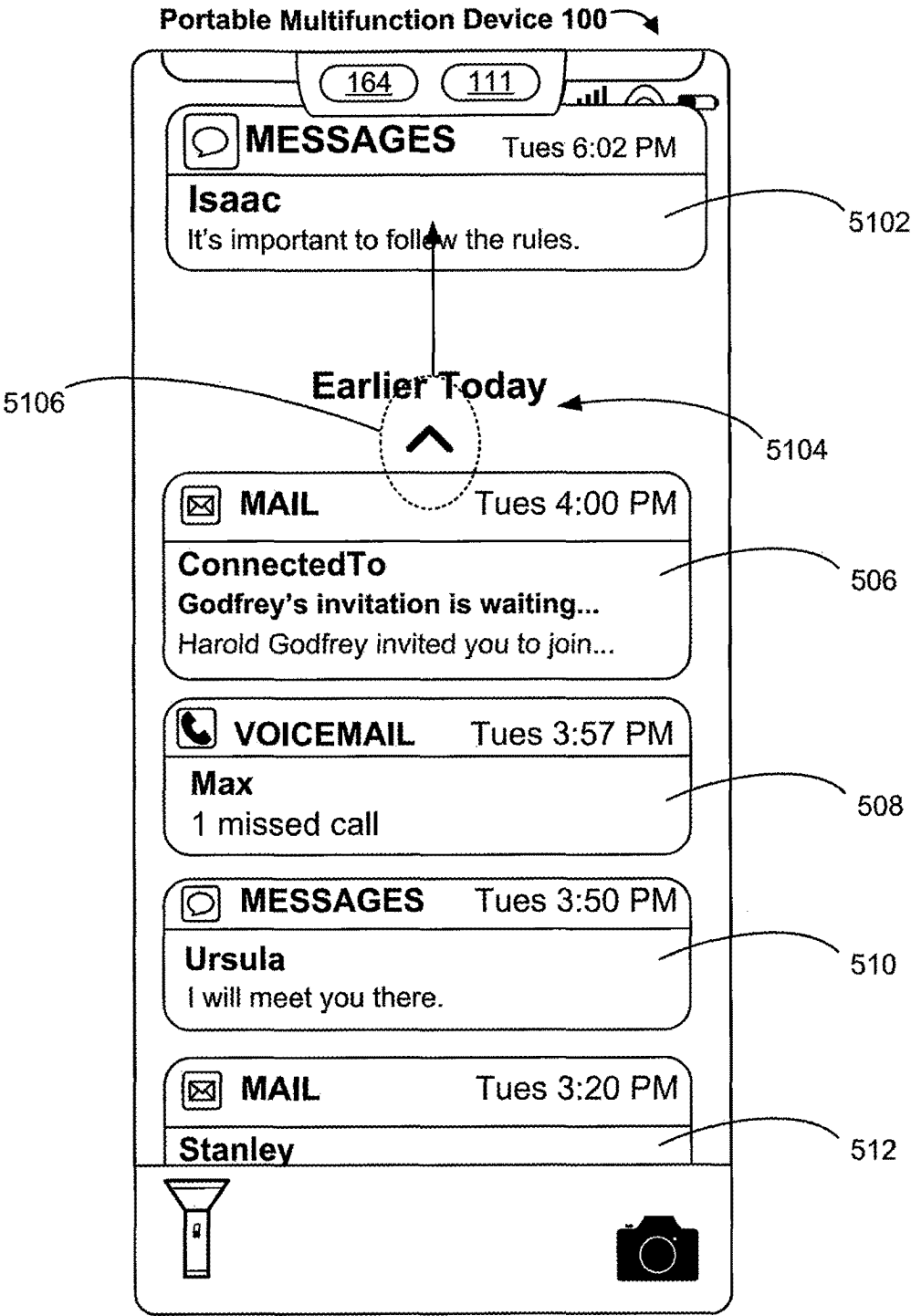


Figure 5BN

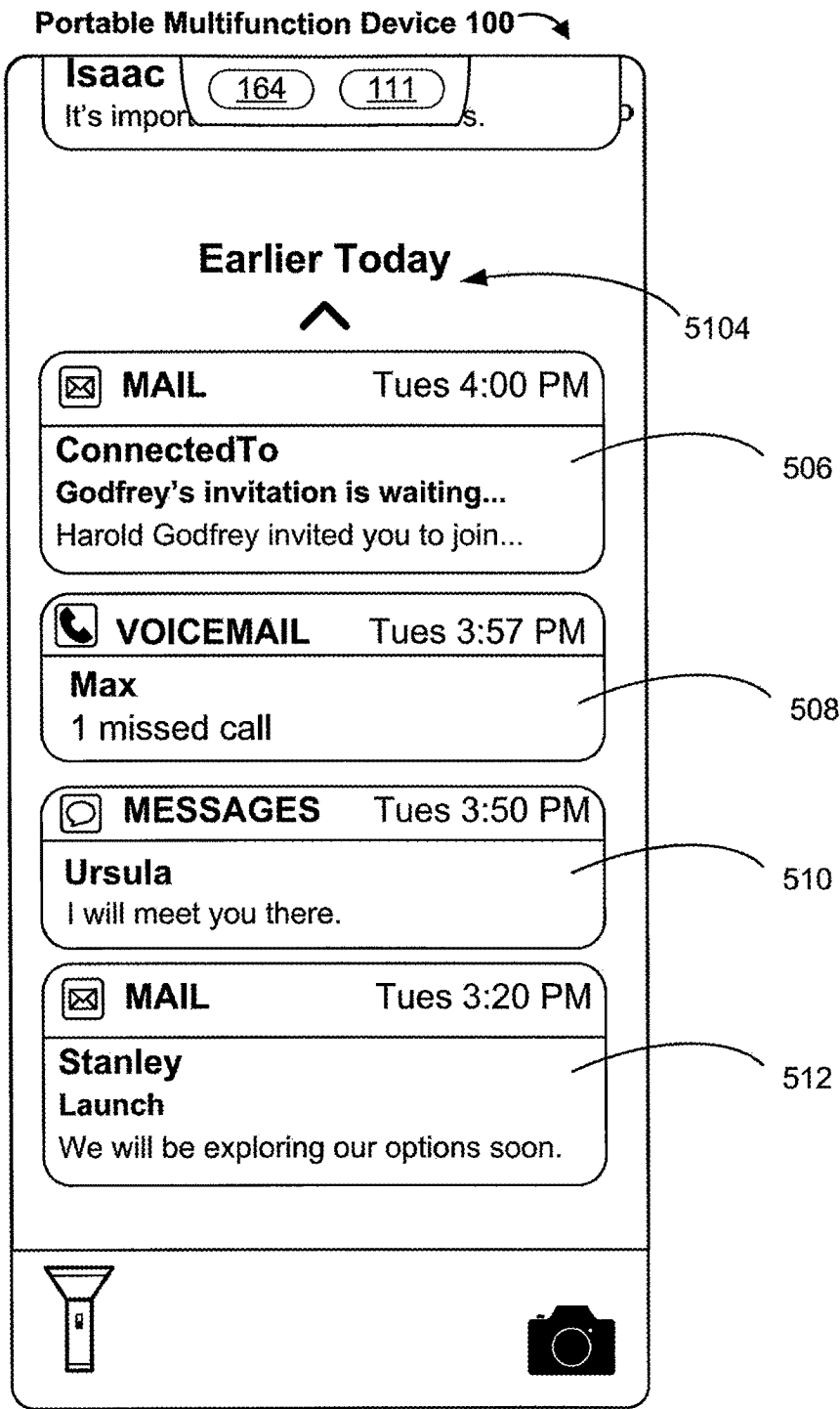


Figure 5BO

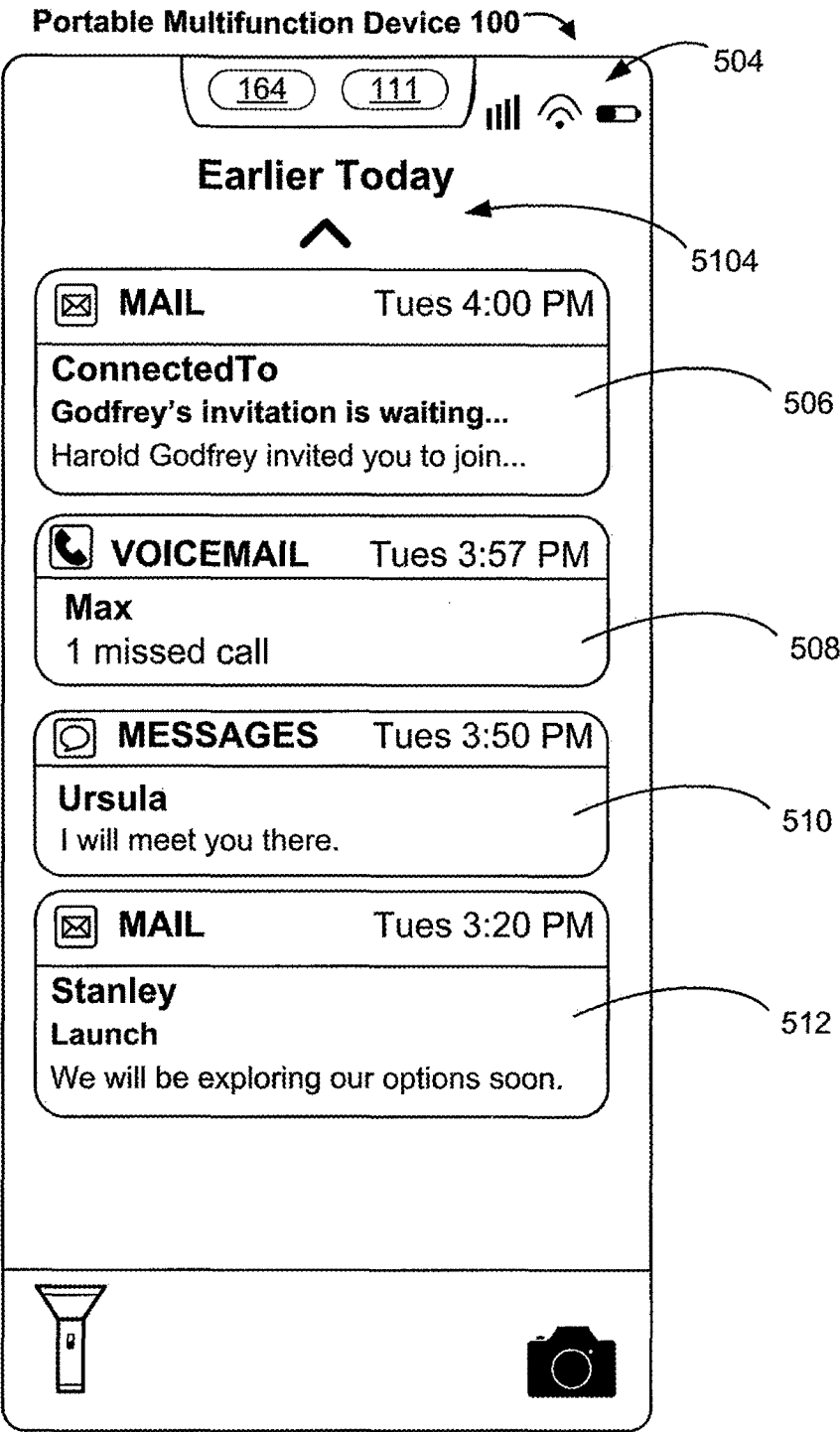


Figure 5BP

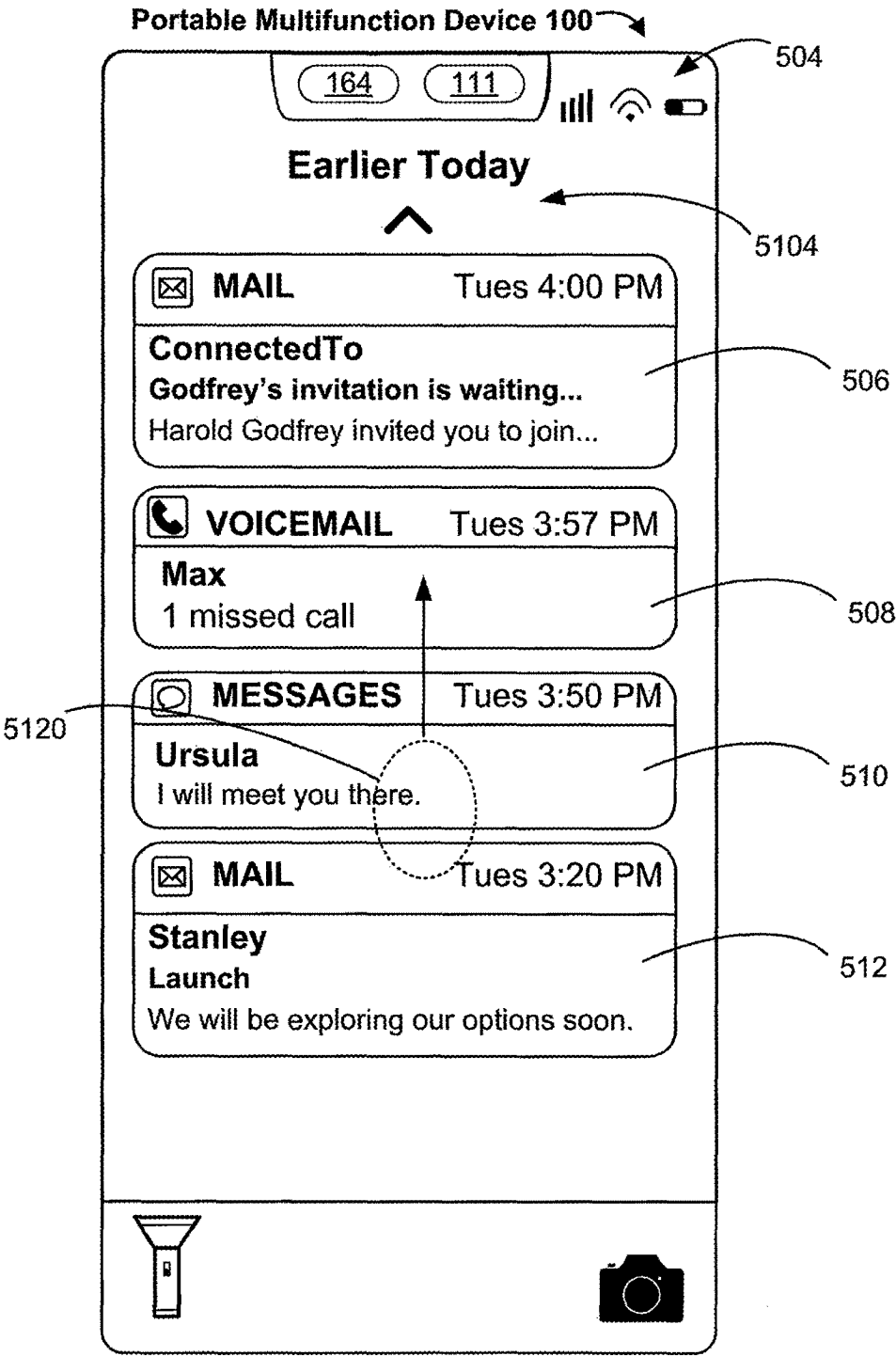


Figure 5BQ



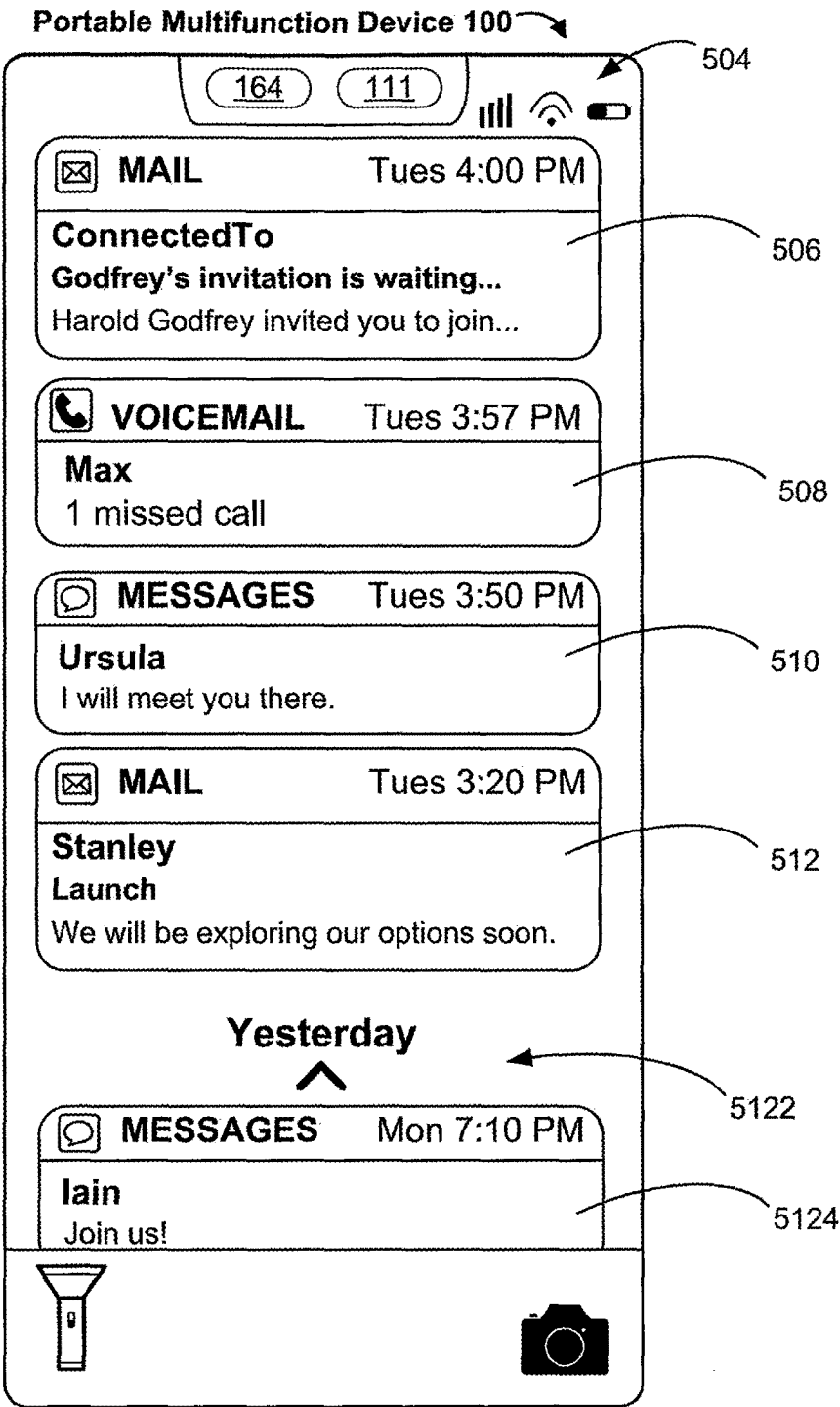


Figure 5BR

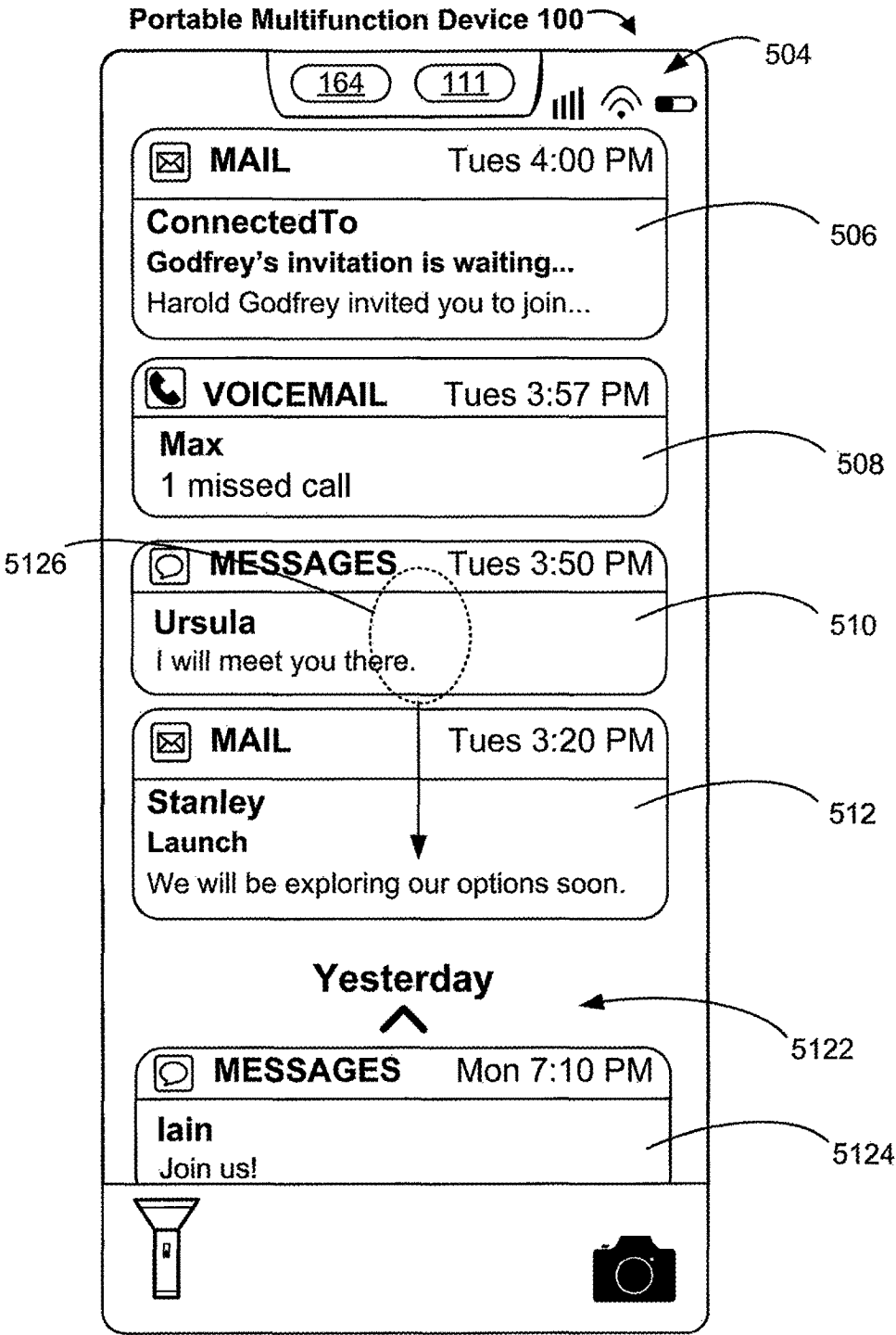


Figure 5BS

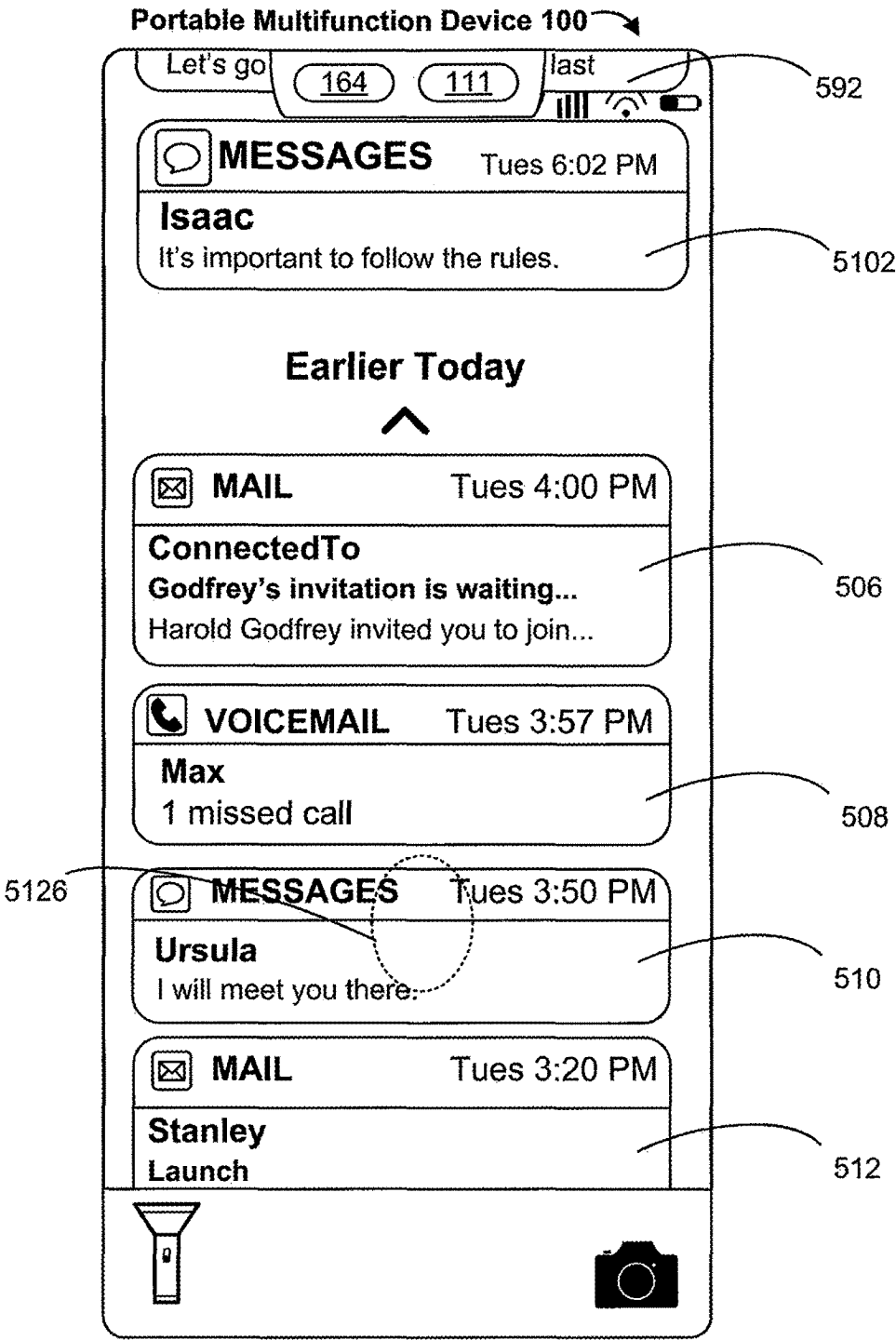


Figure 5BT

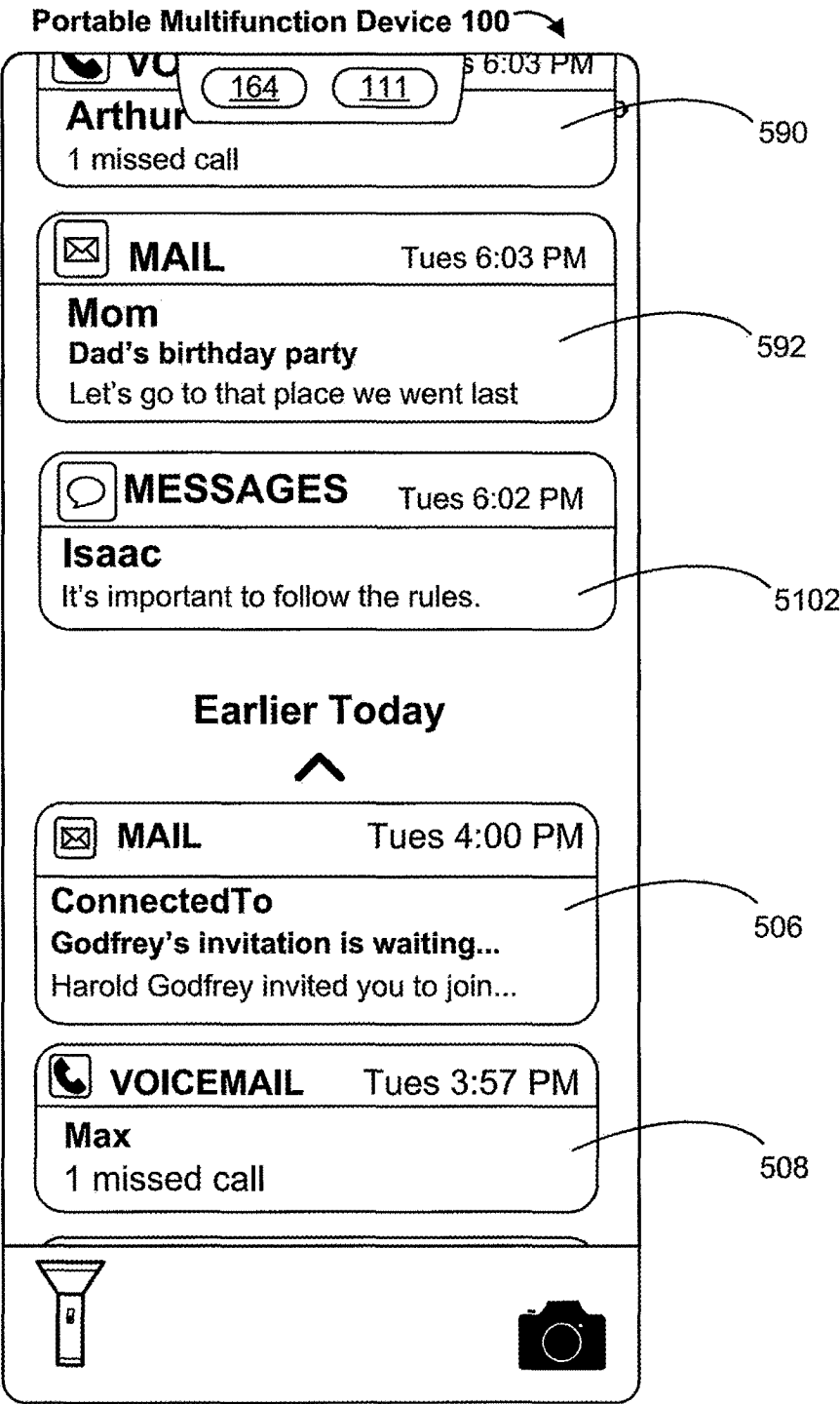


Figure 5BU

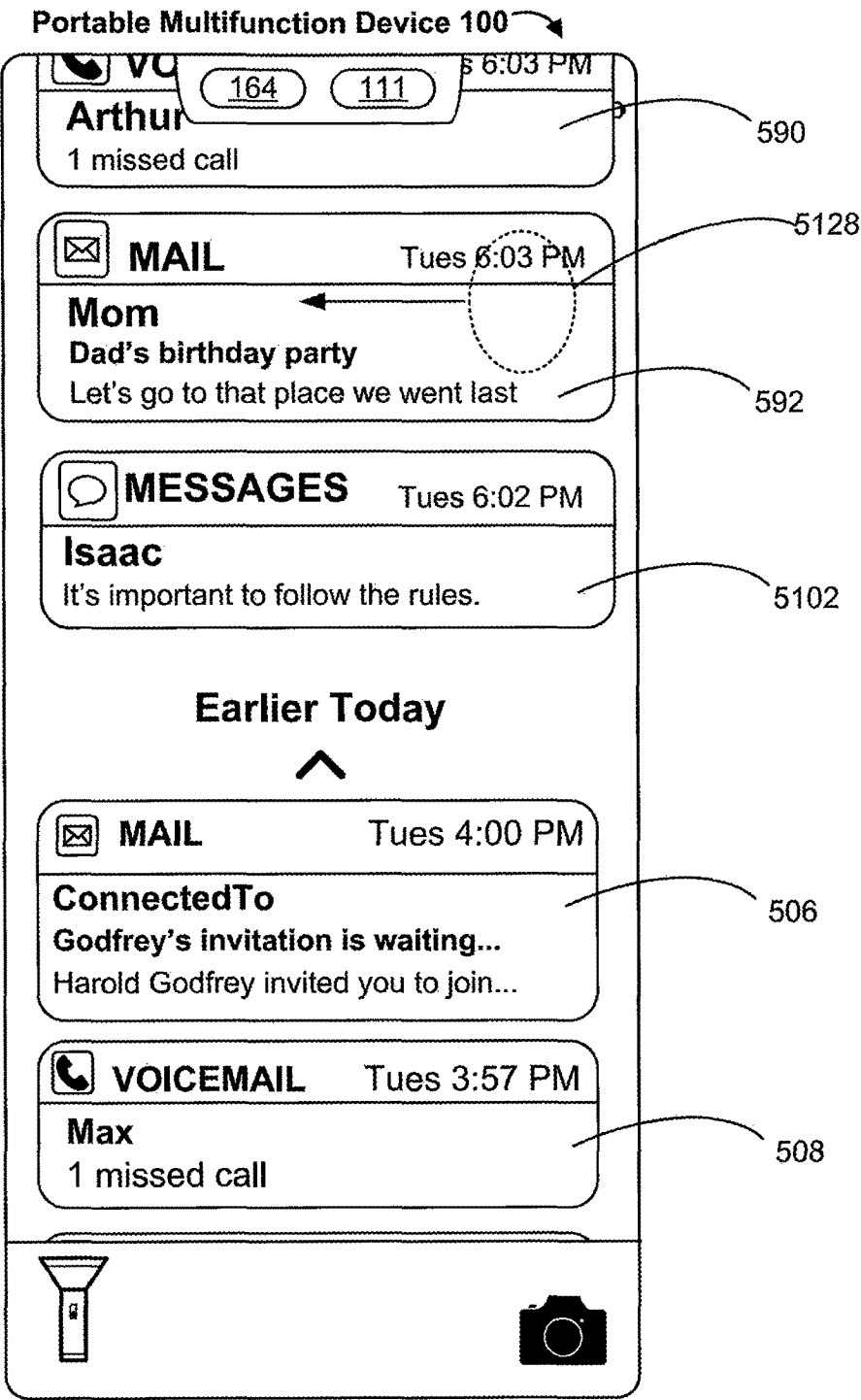


Figure 5BV

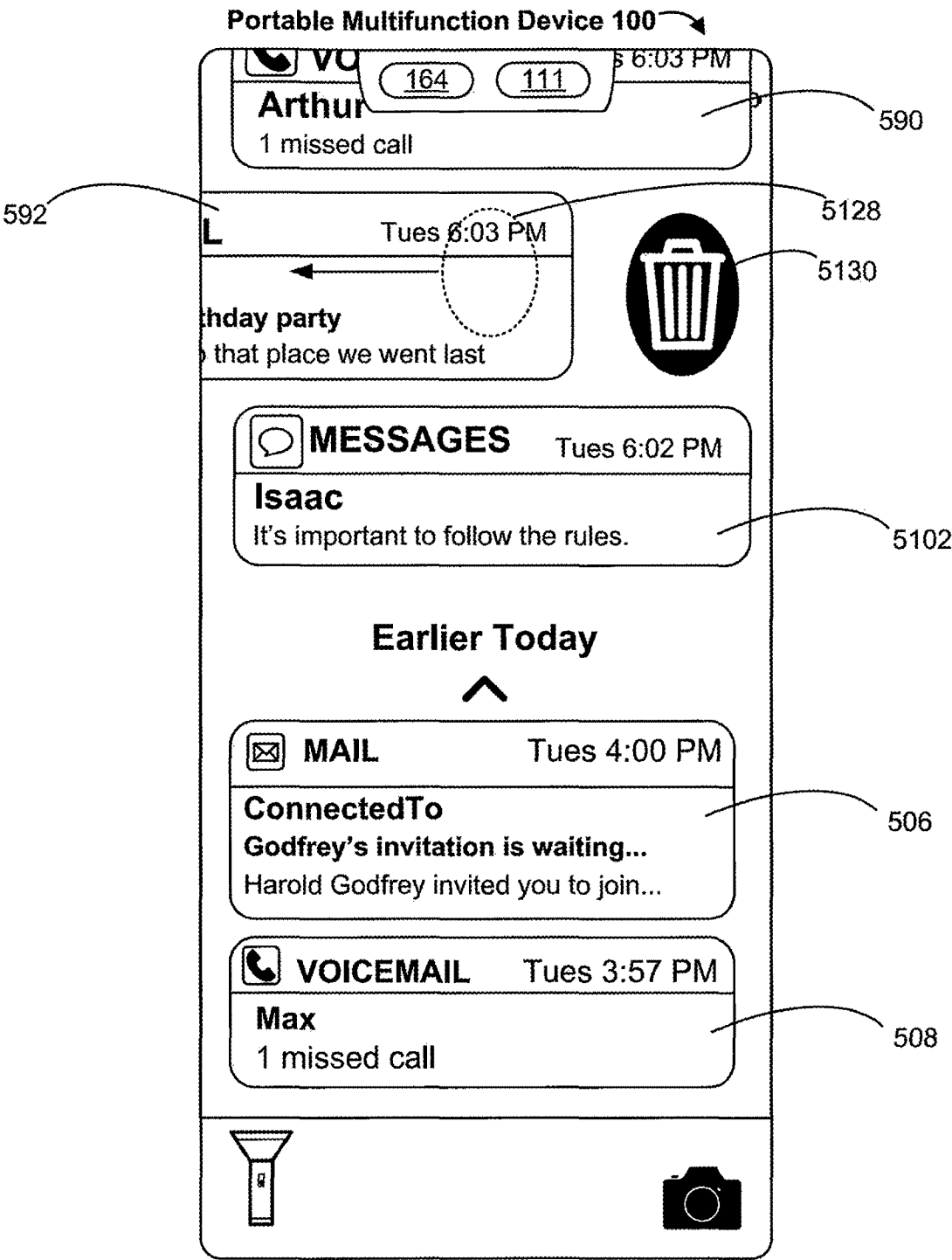


Figure 5BW



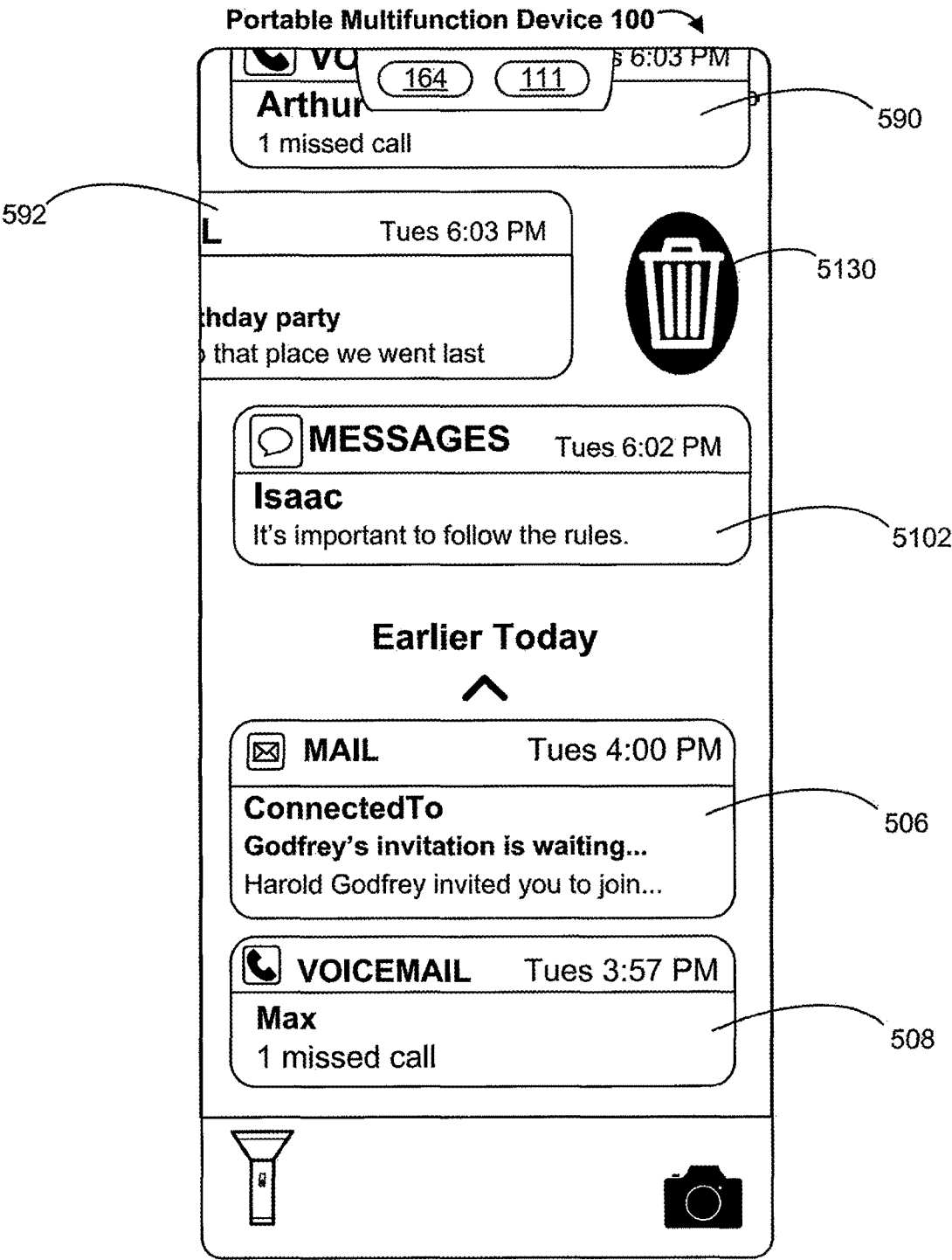


Figure 5BX

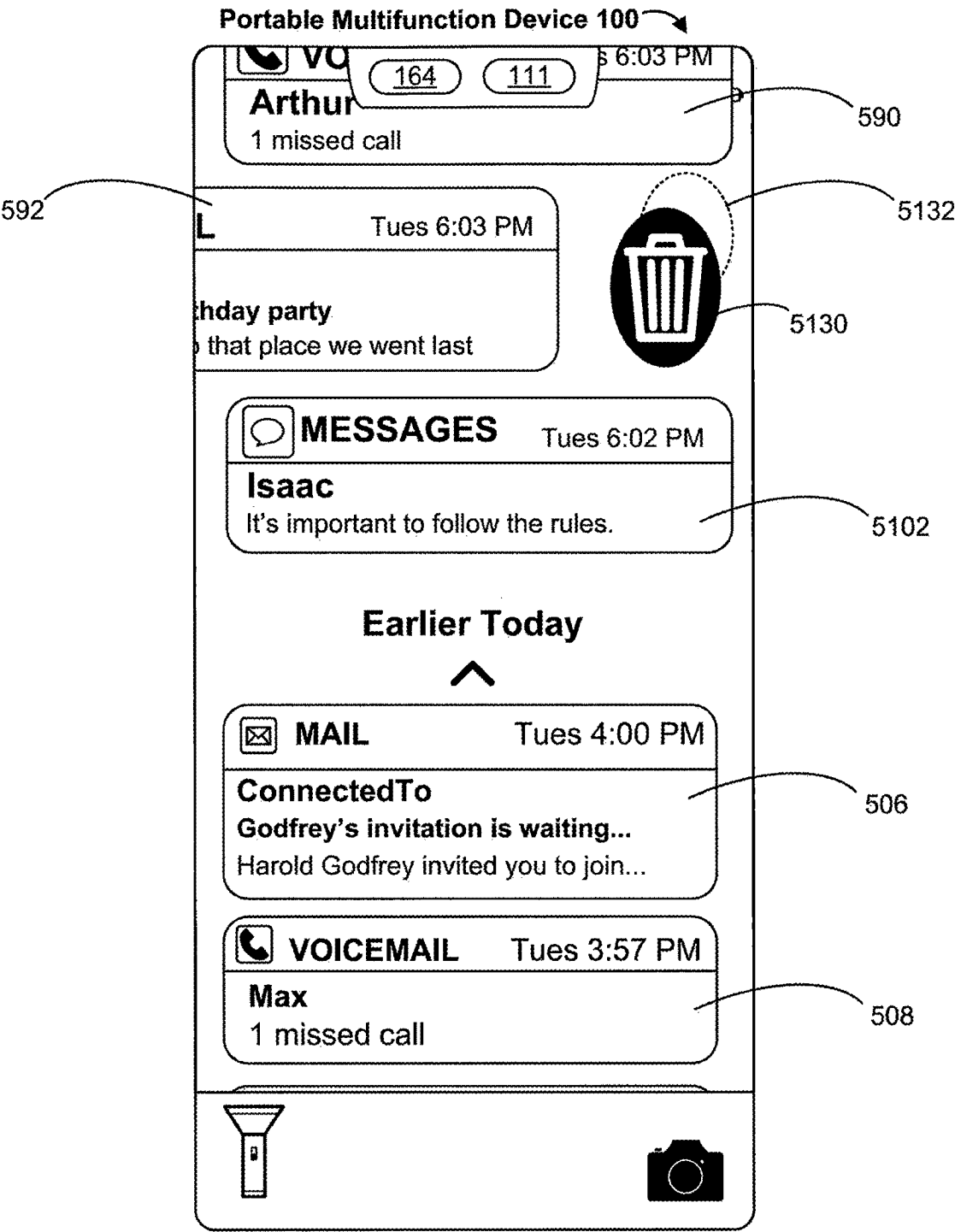


Figure 5BY

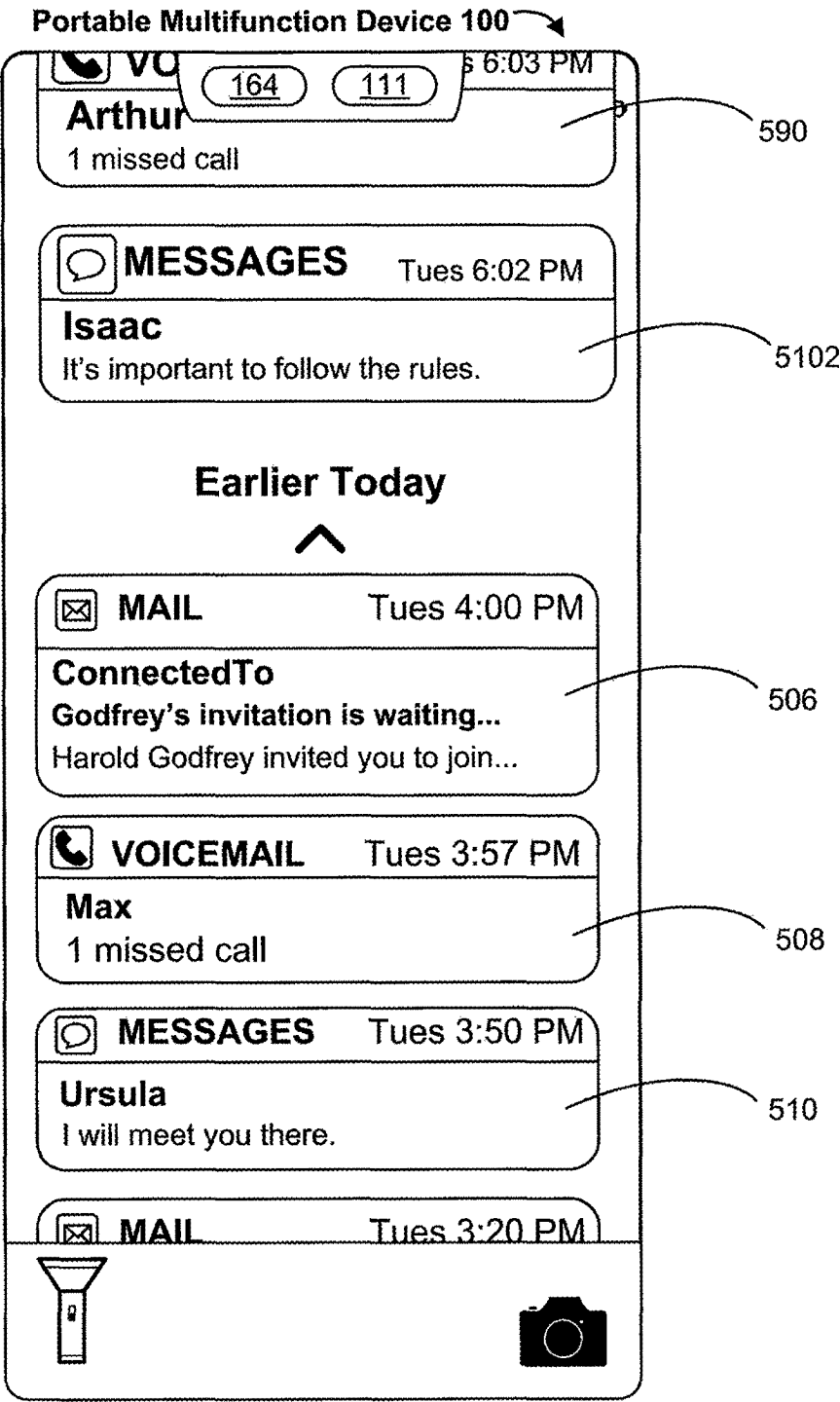


Figure 5BZ

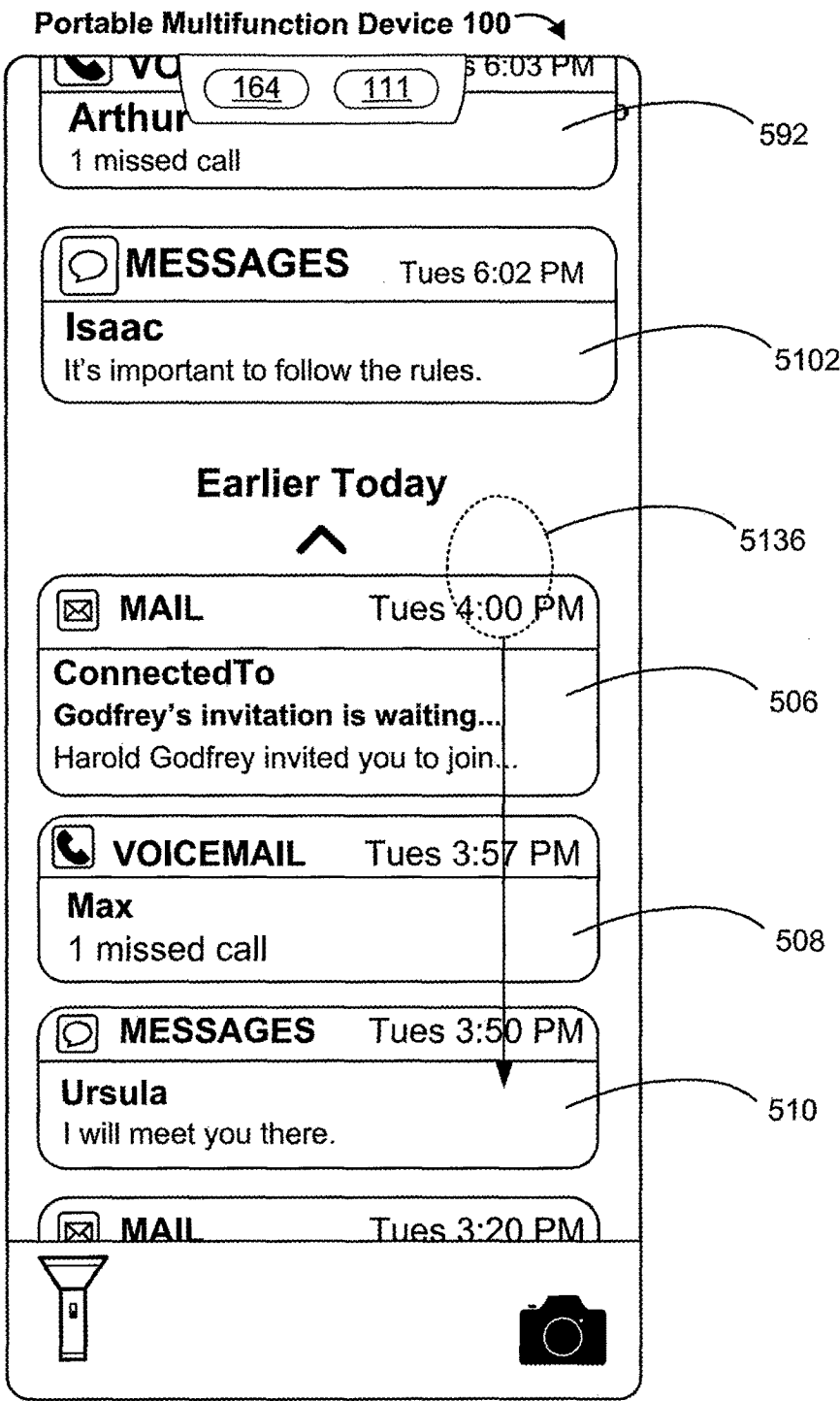


Figure 5CA

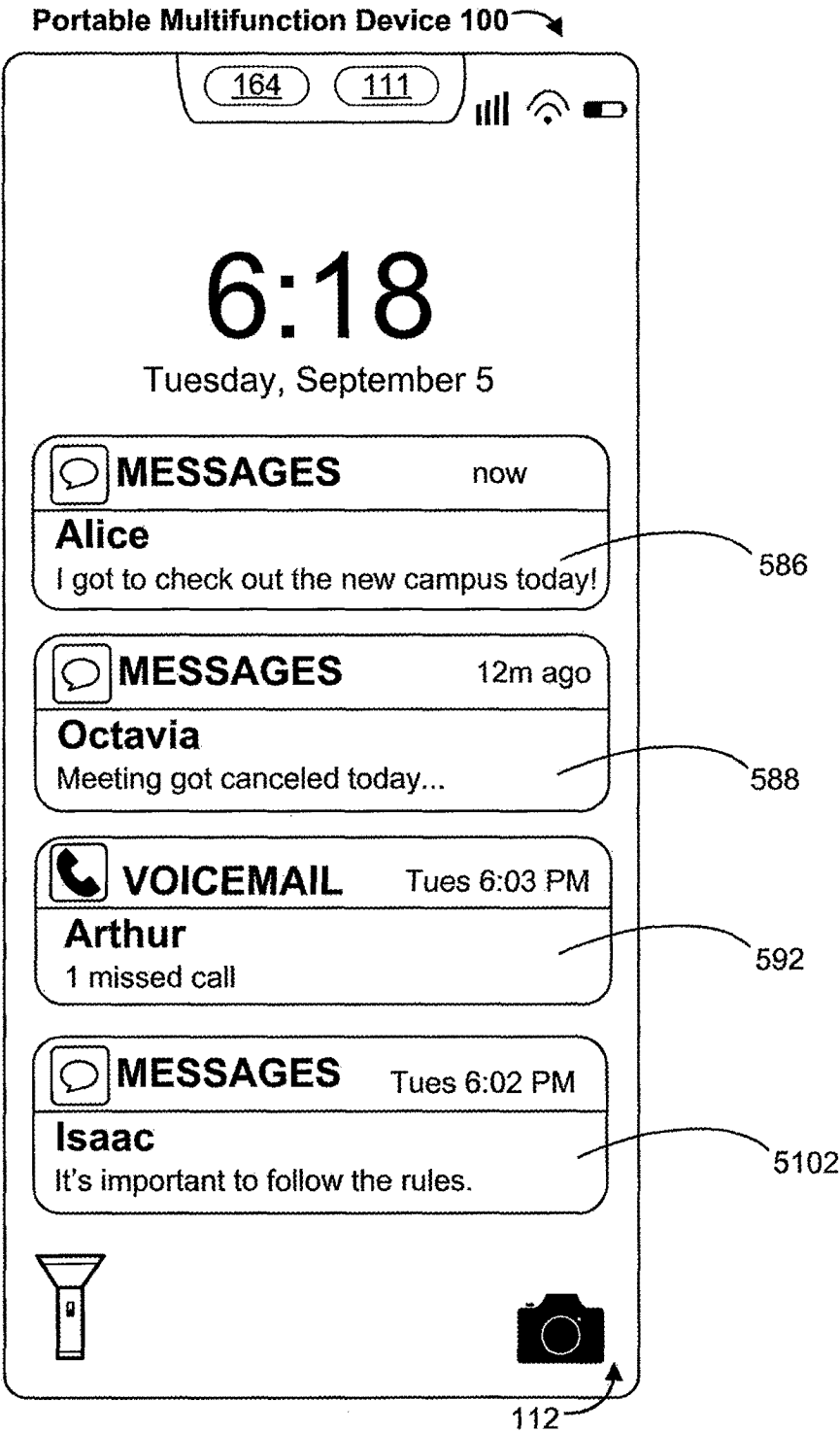


Figure 5CB

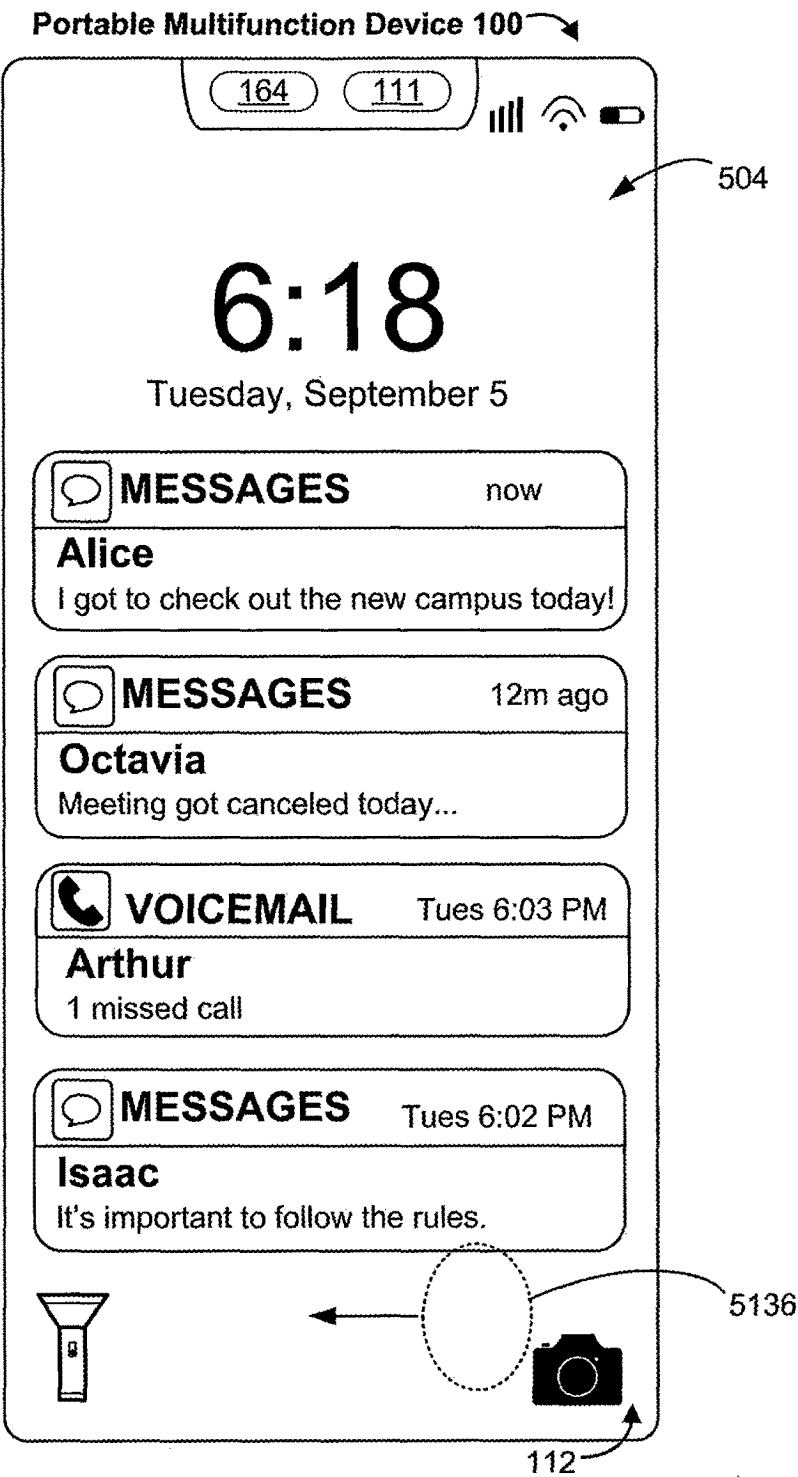


Figure 5CC



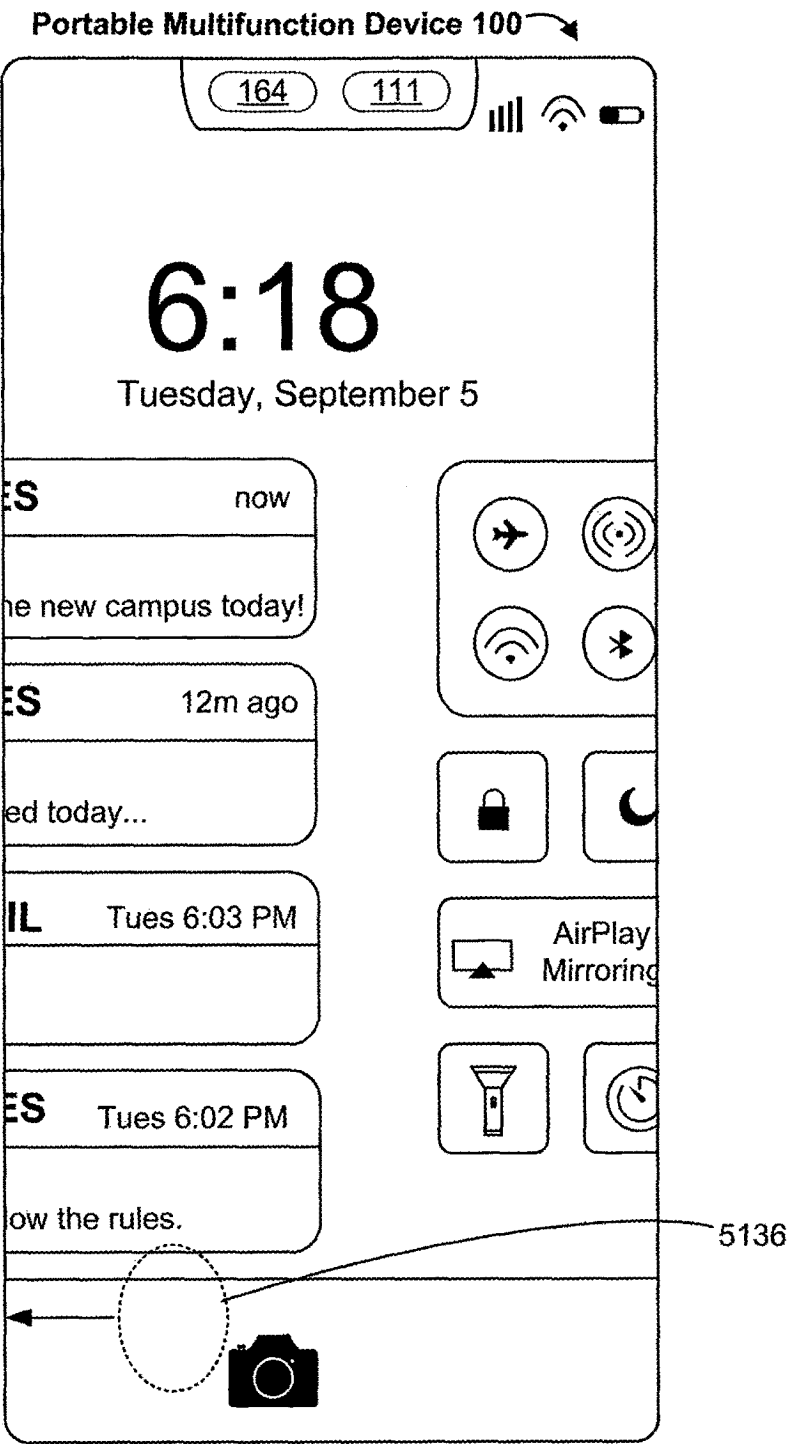


Figure 5CD

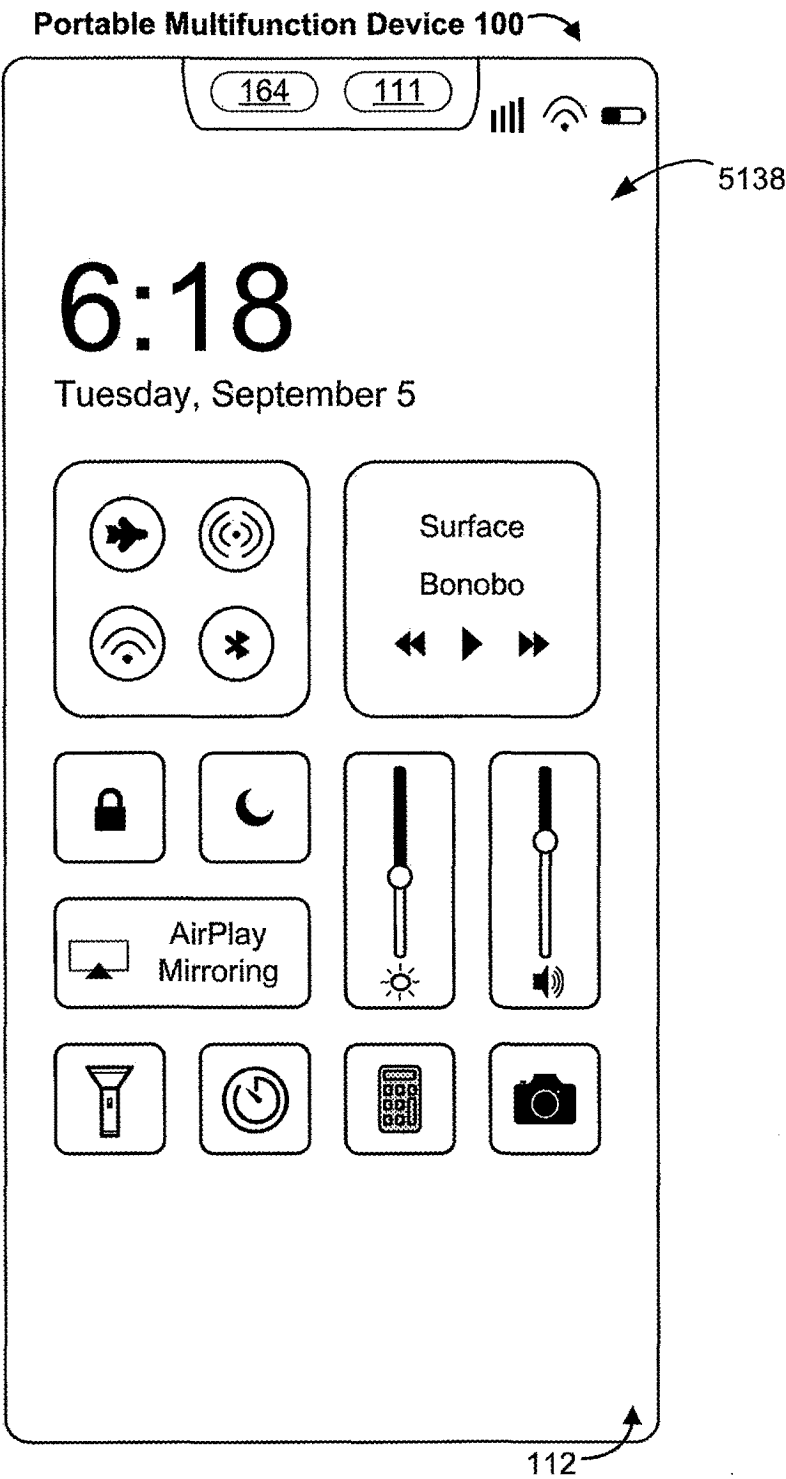


Figure 5CE



Figure 5CF

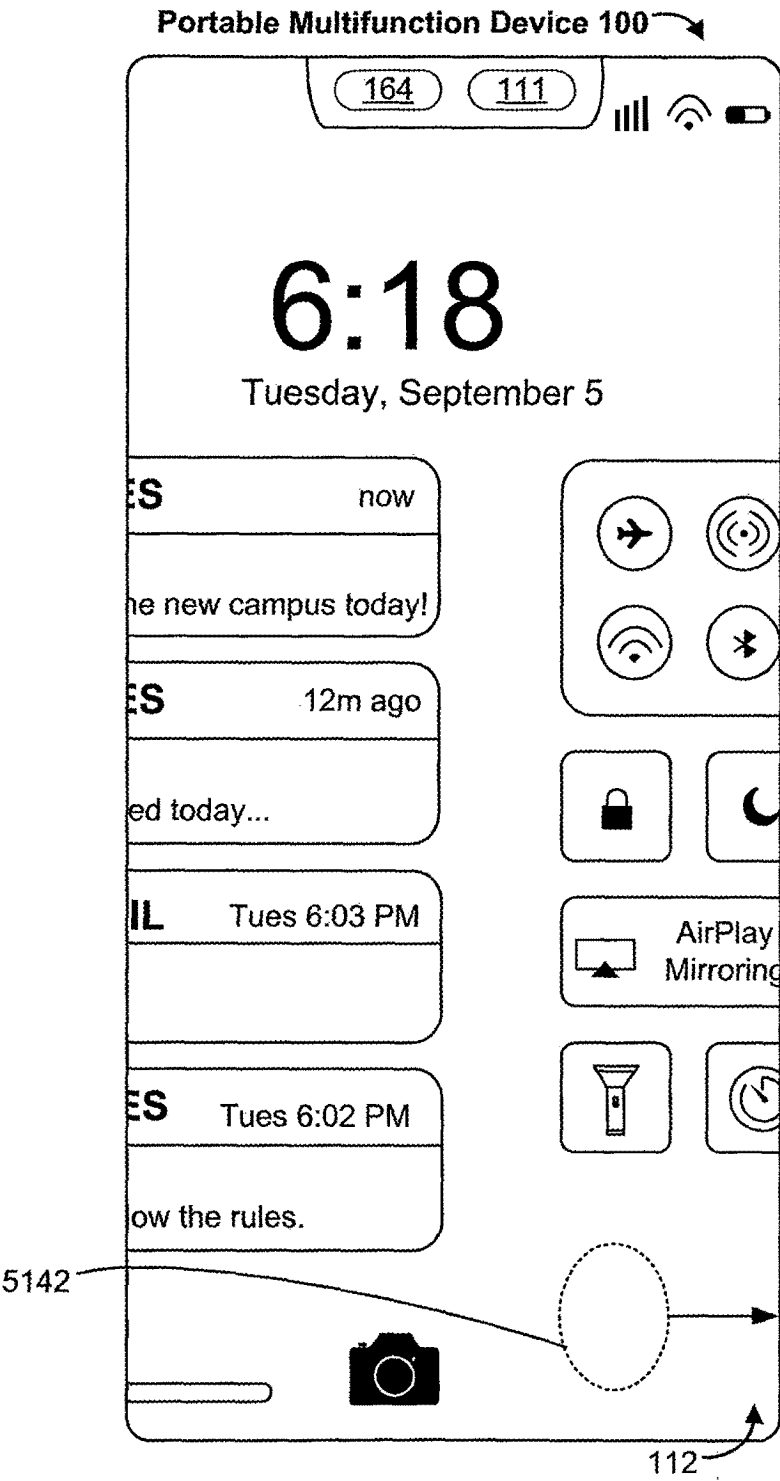


Figure 5CG

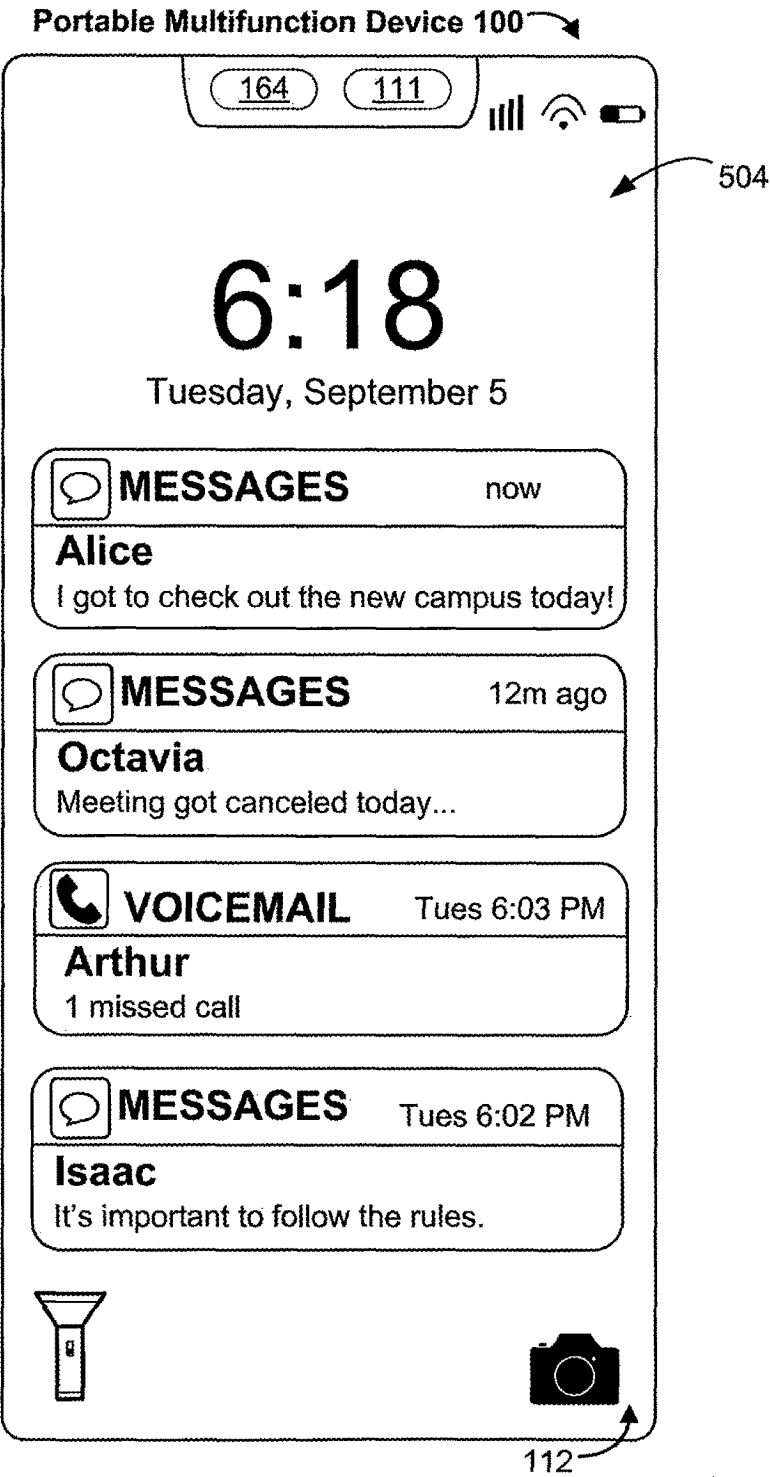


Figure 5CH

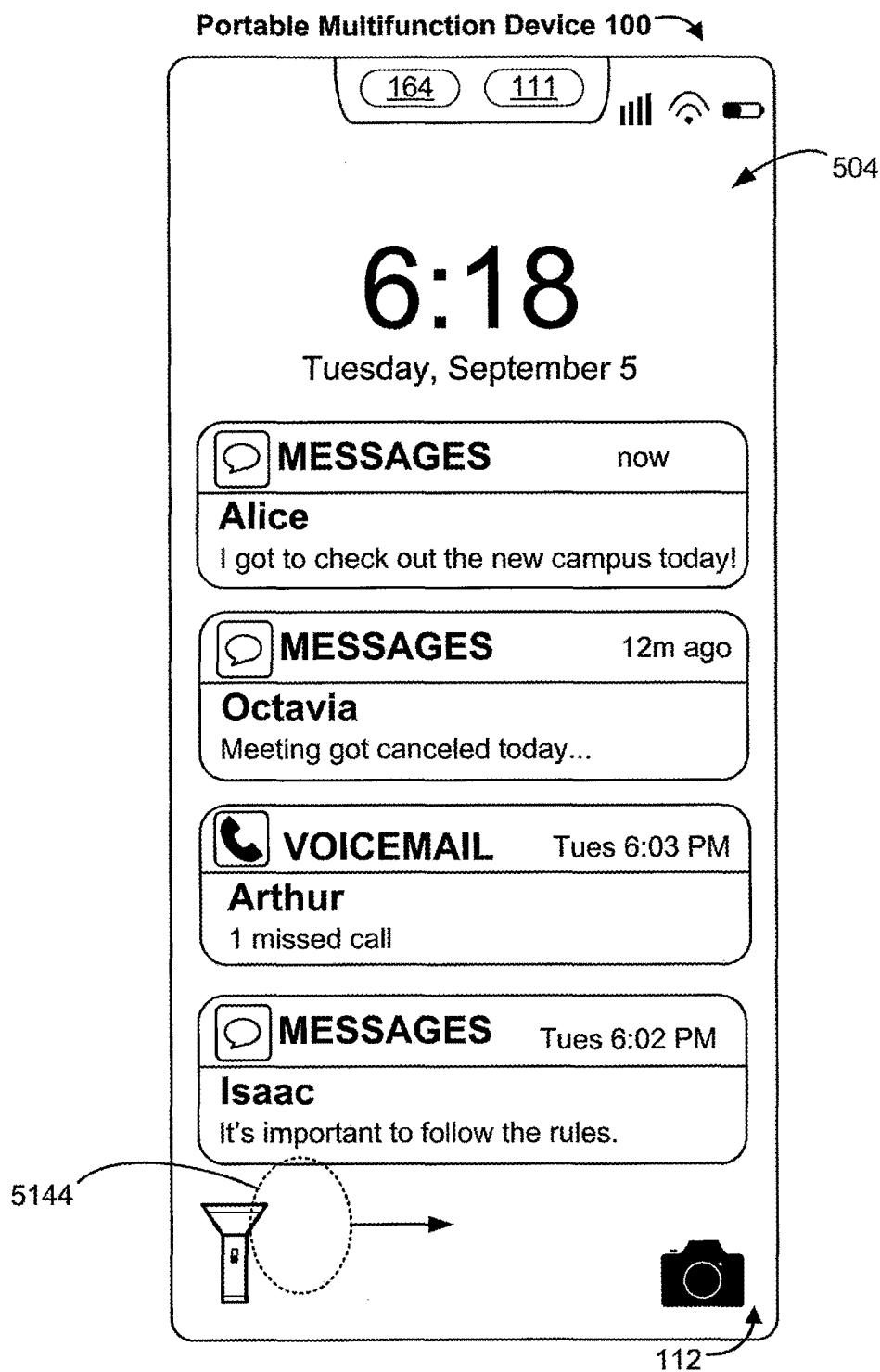


Figure 5C



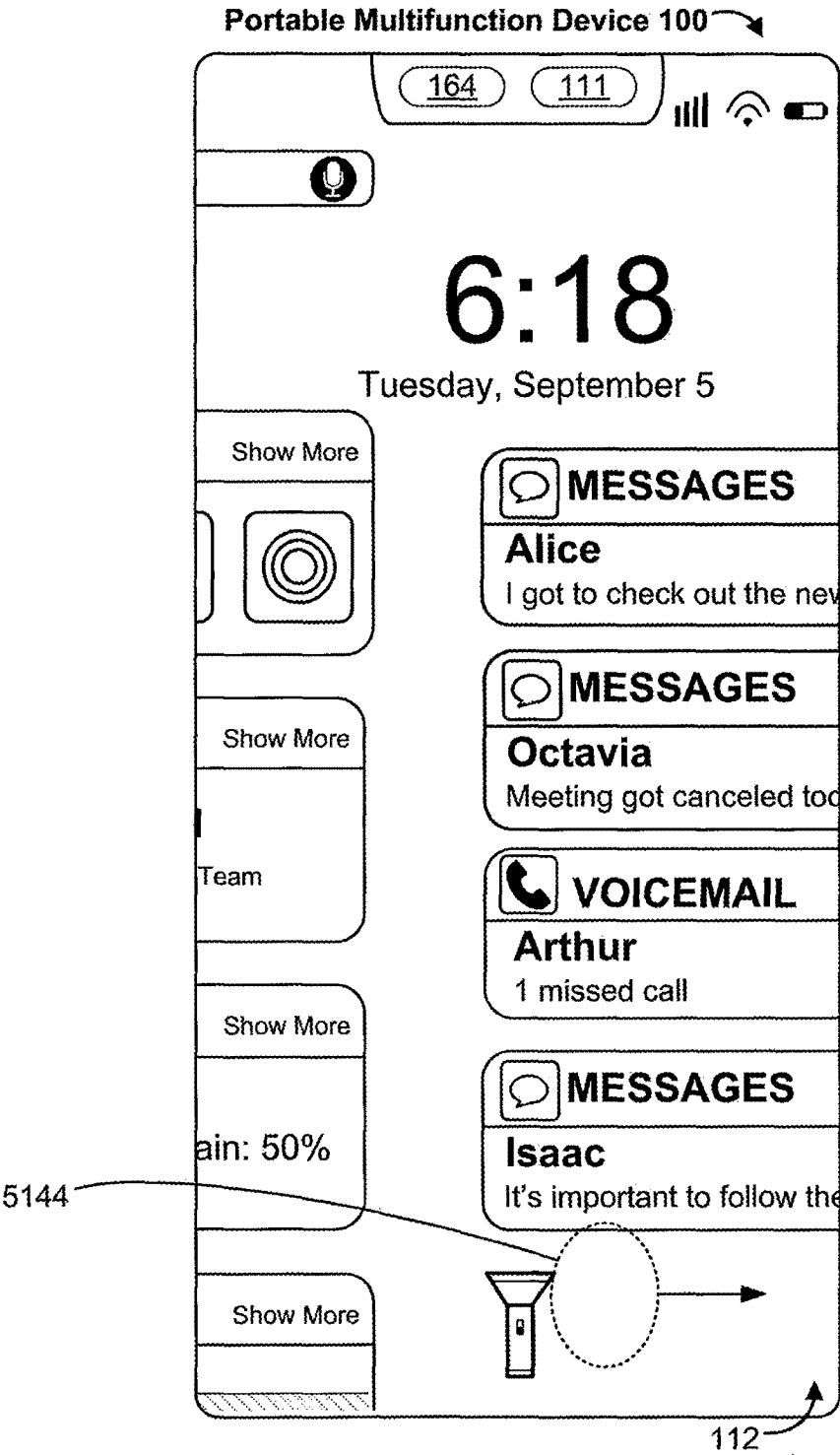


Figure 5CJ

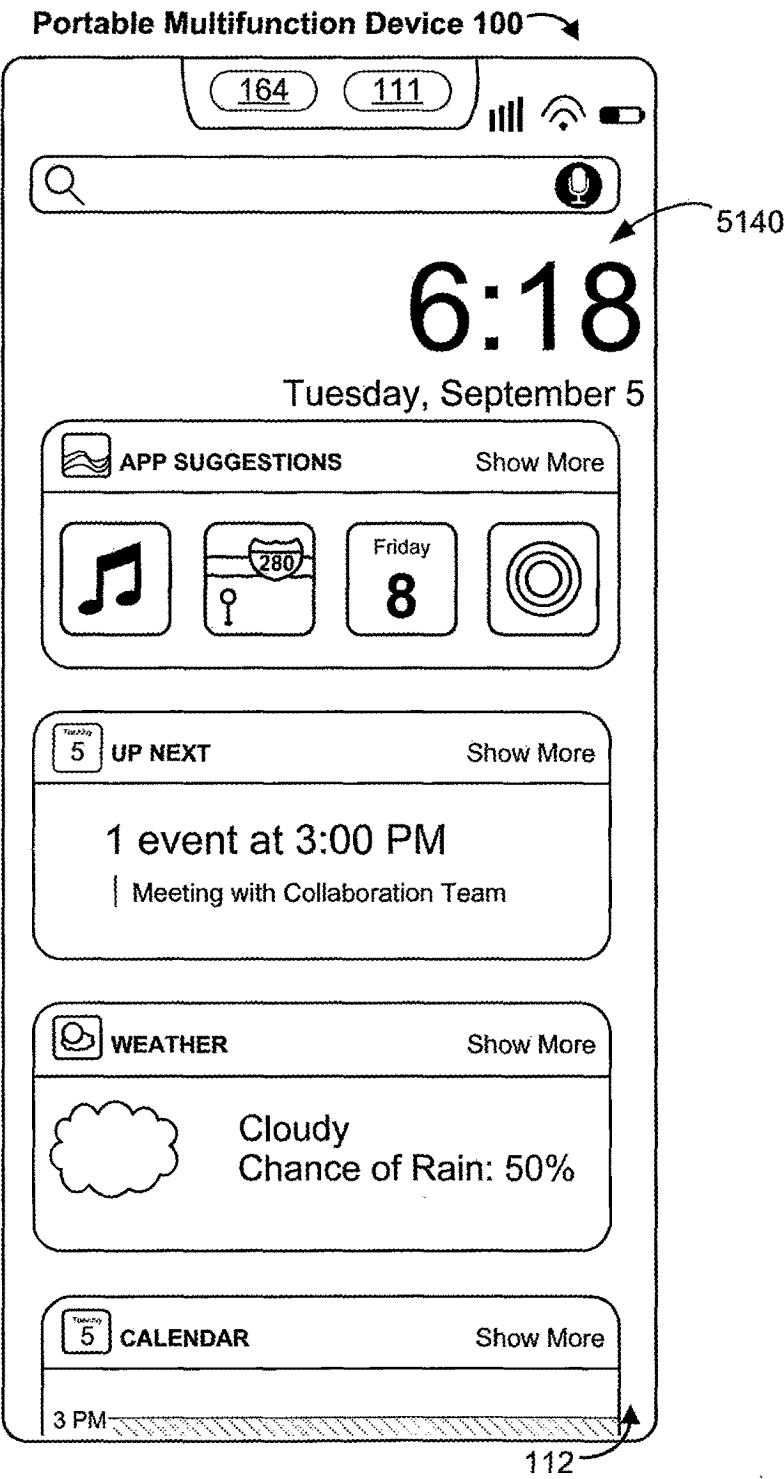


Figure 5CK

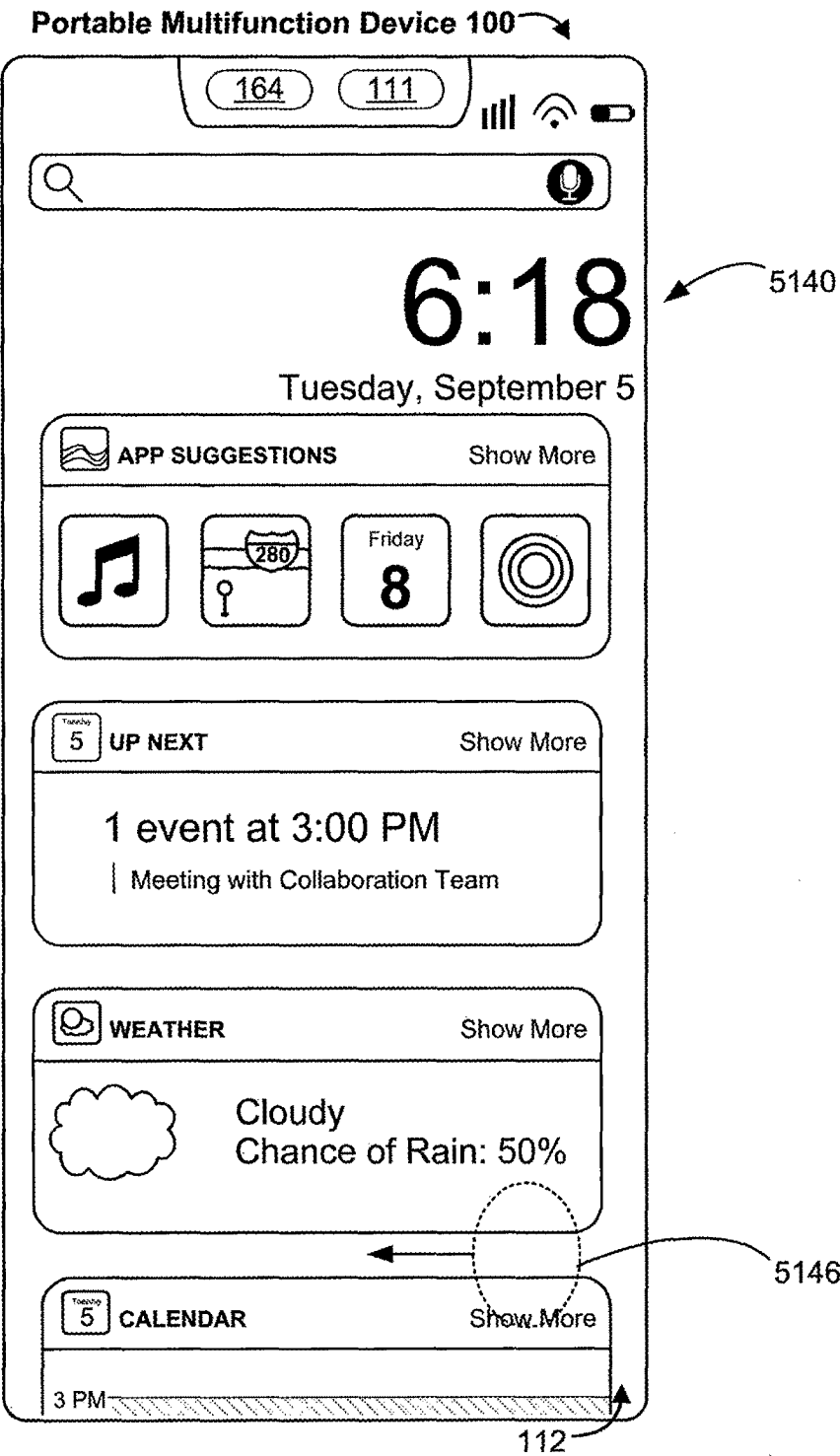


Figure 5CL

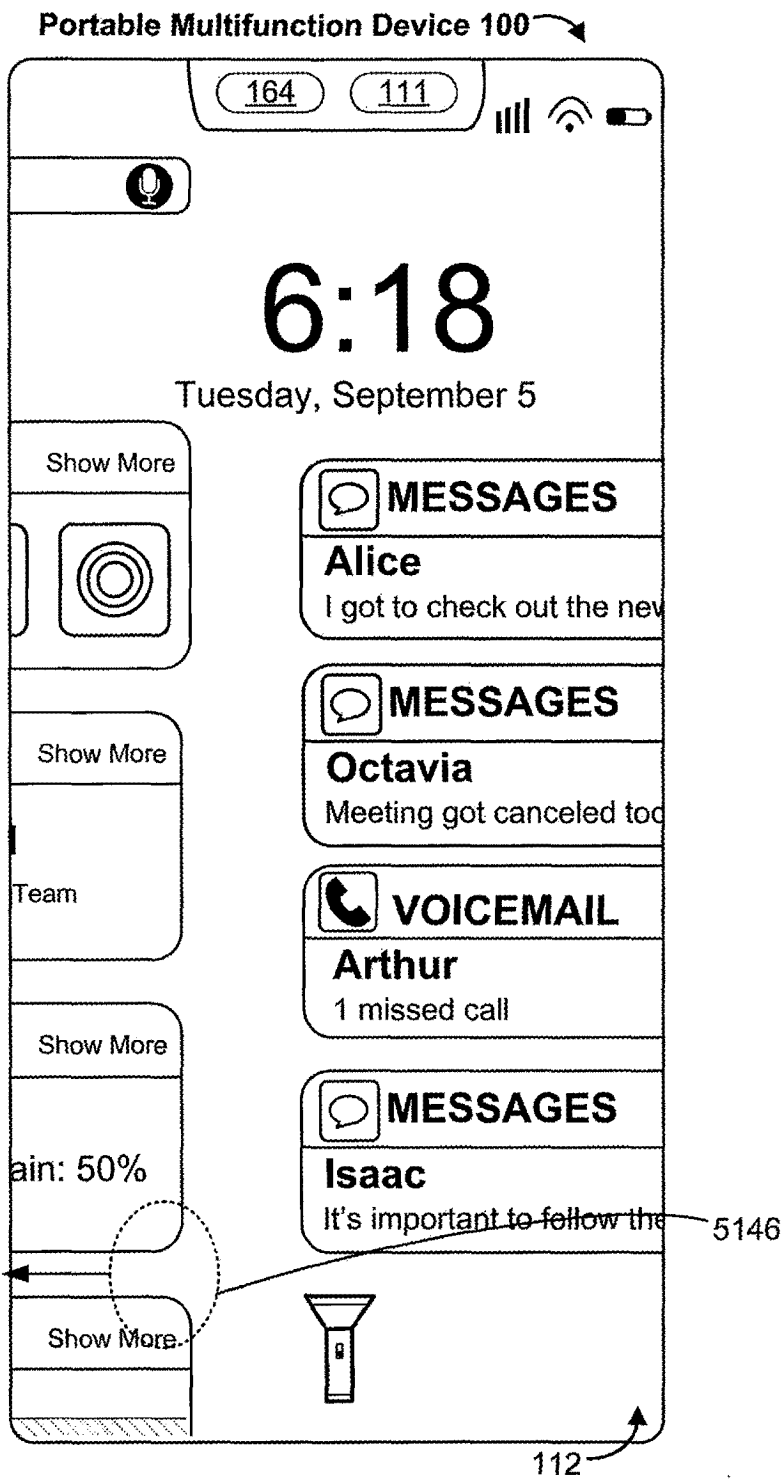


Figure 5CM

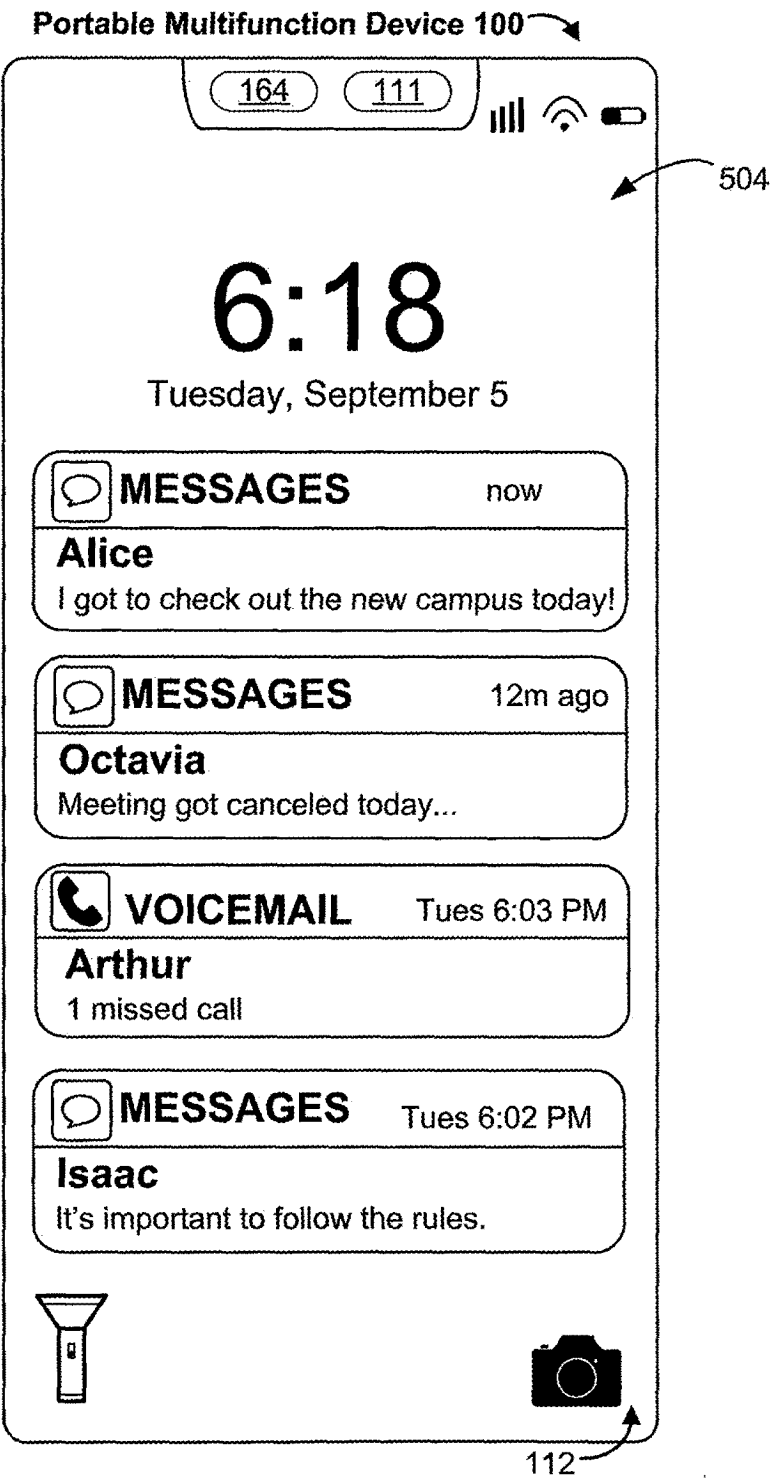


Figure 5CN

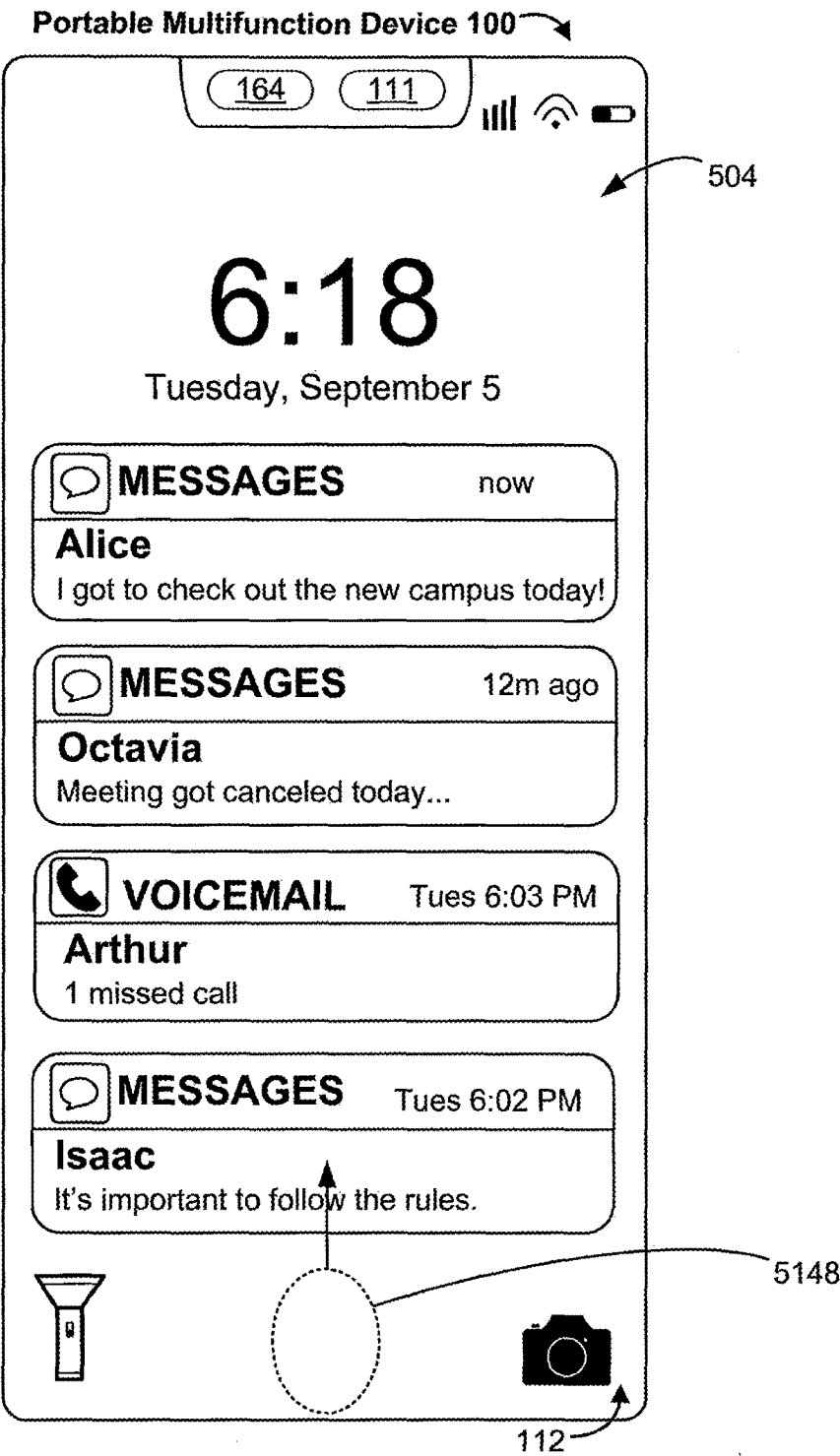


Figure 5CO



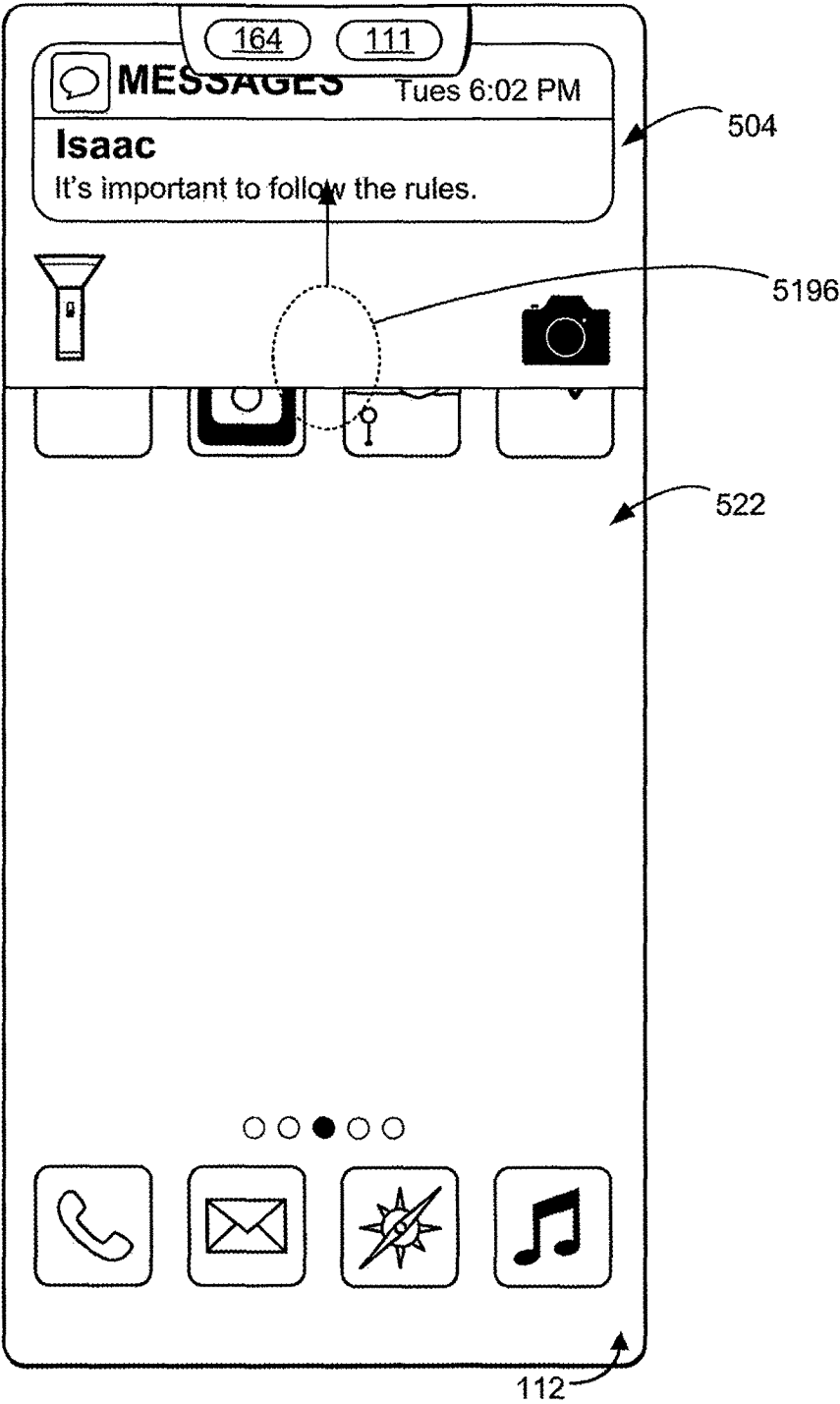


Figure 5CP

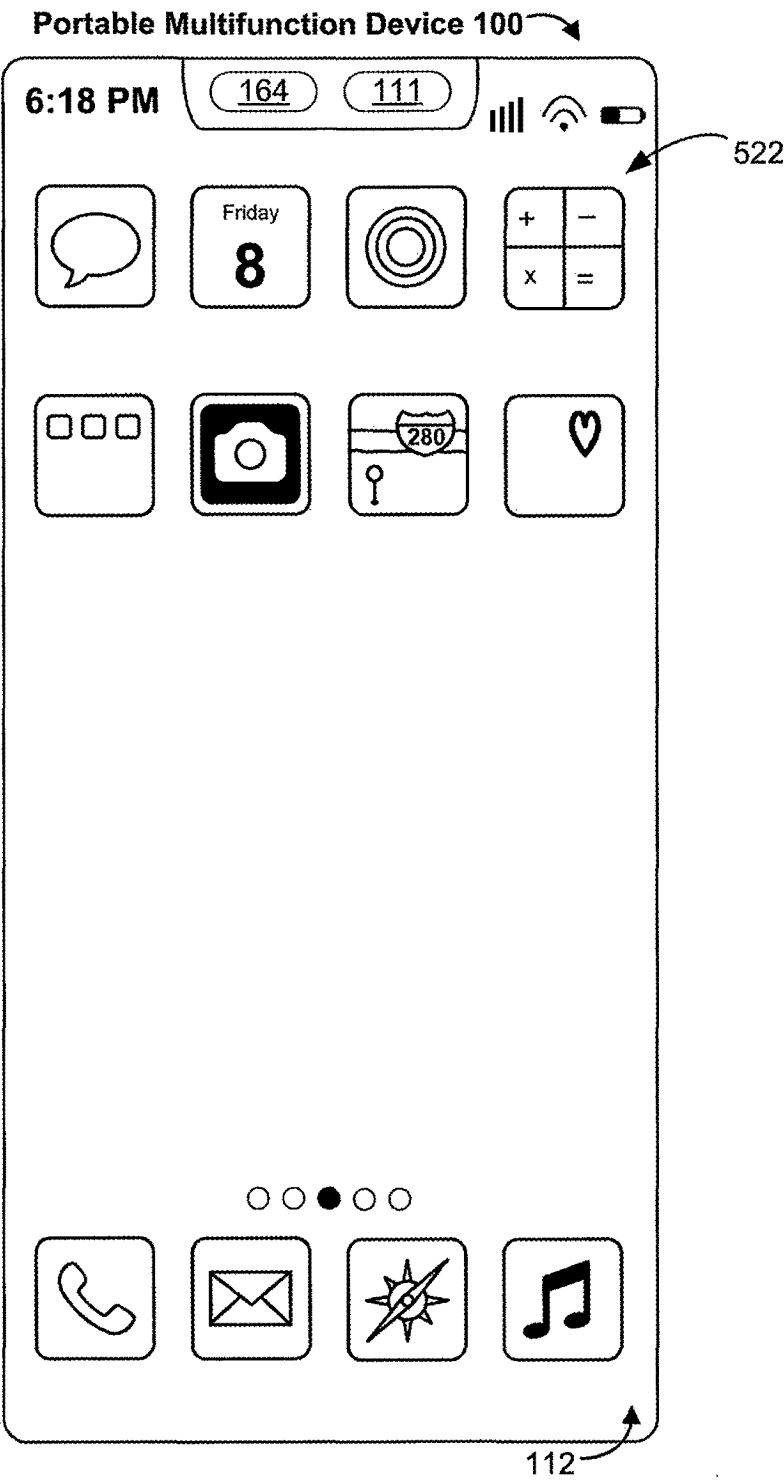


Figure 5CQ

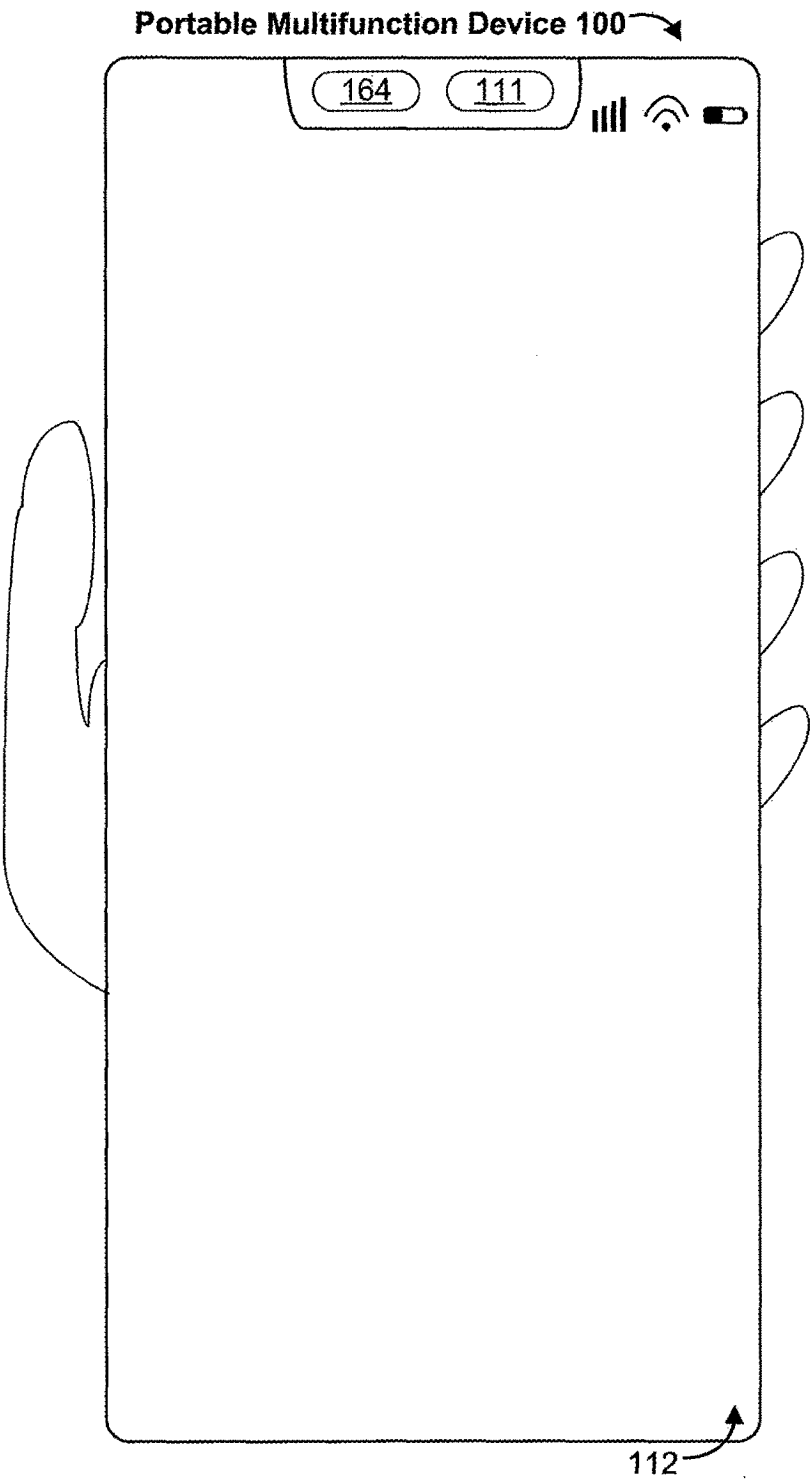


Figure 5CR

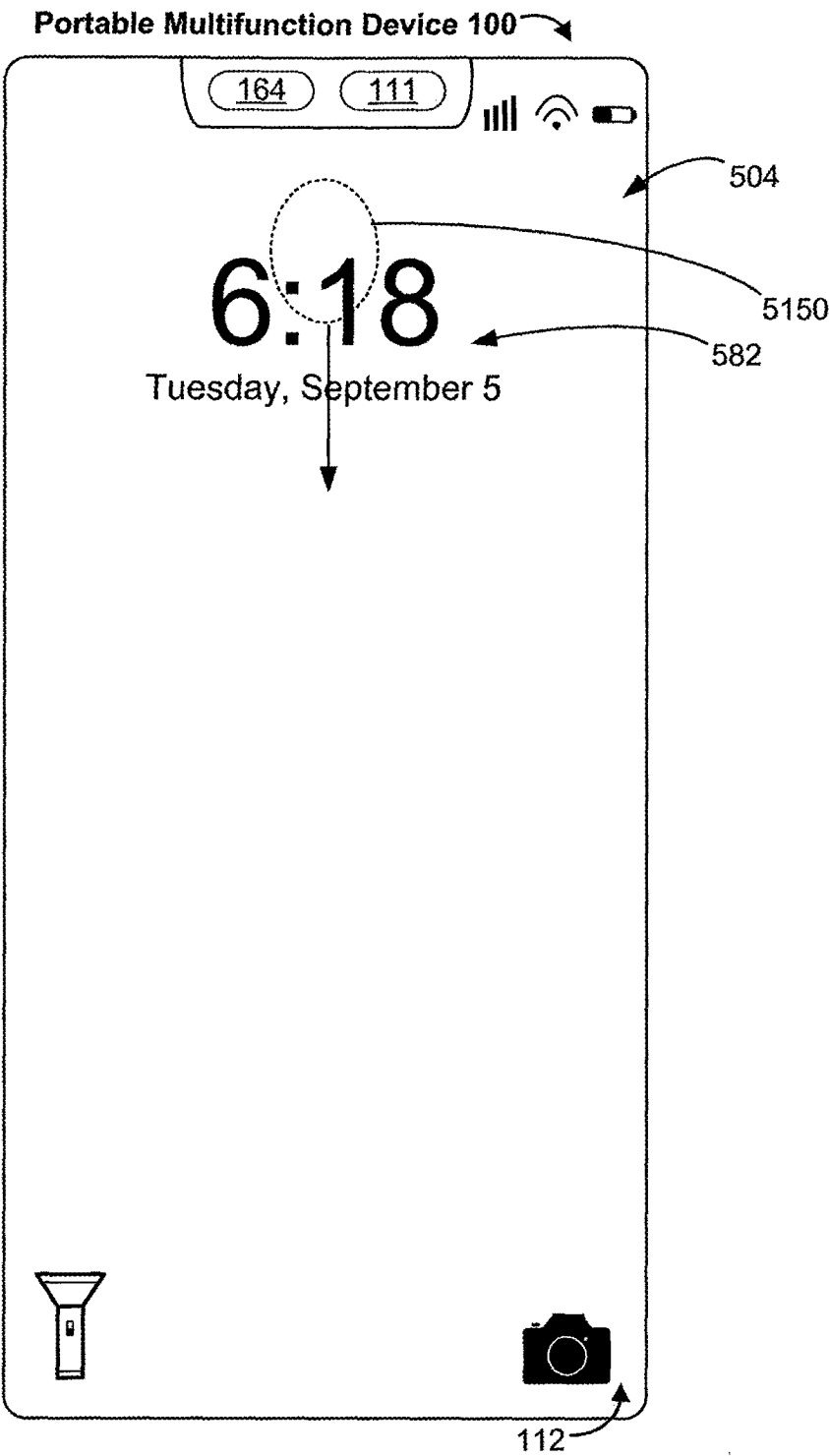


Figure 5CS

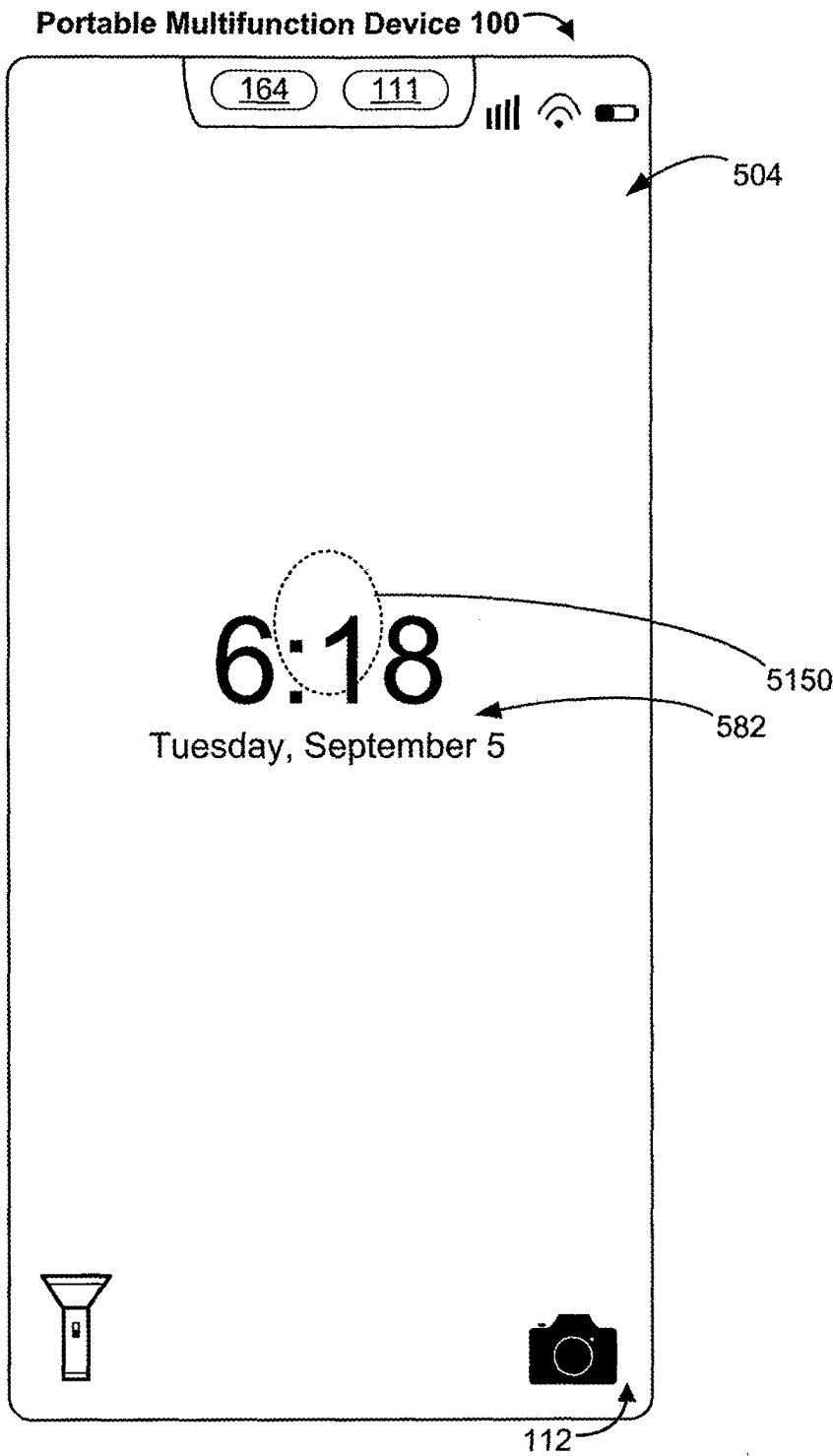


Figure 5CT

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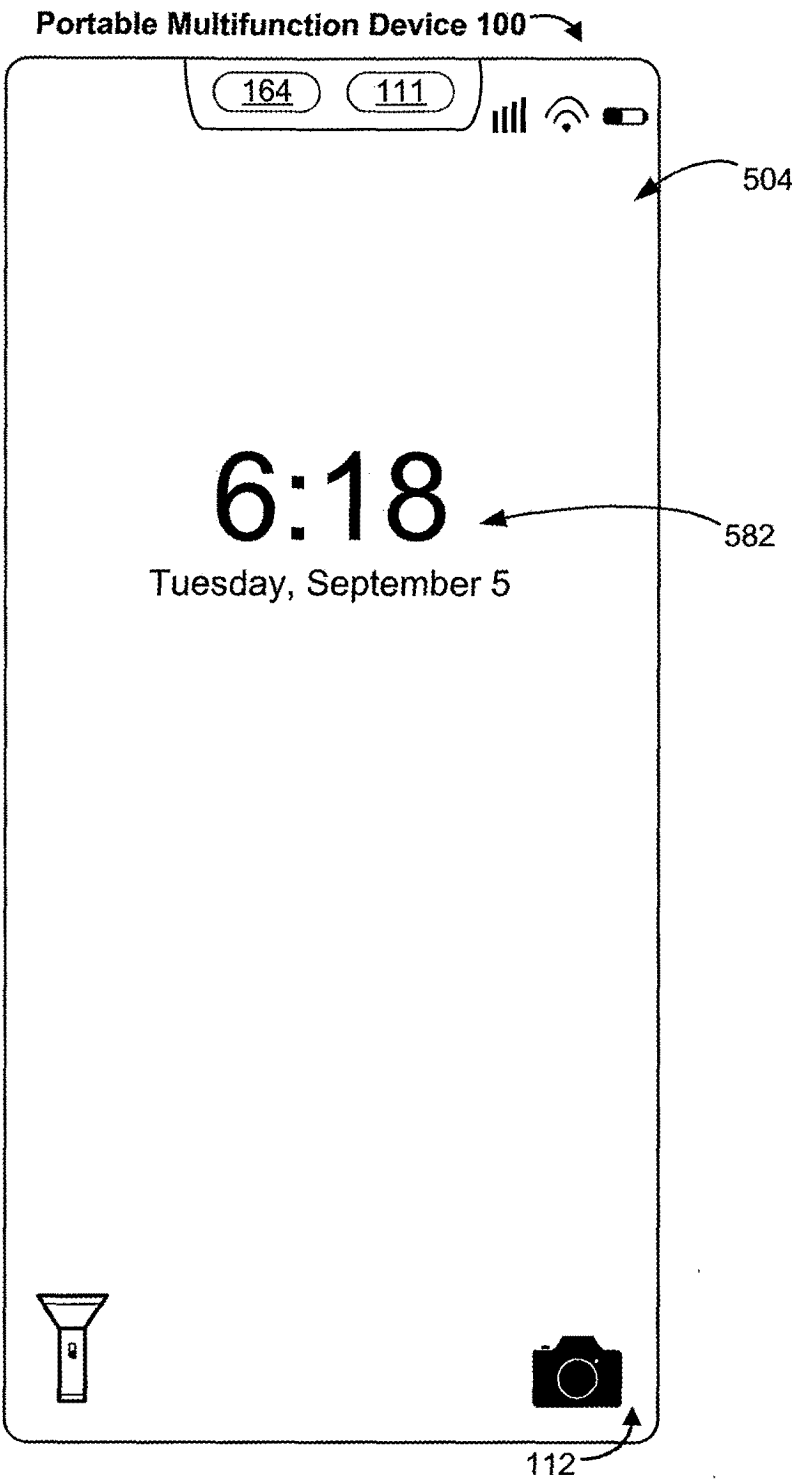


Figure 5CU



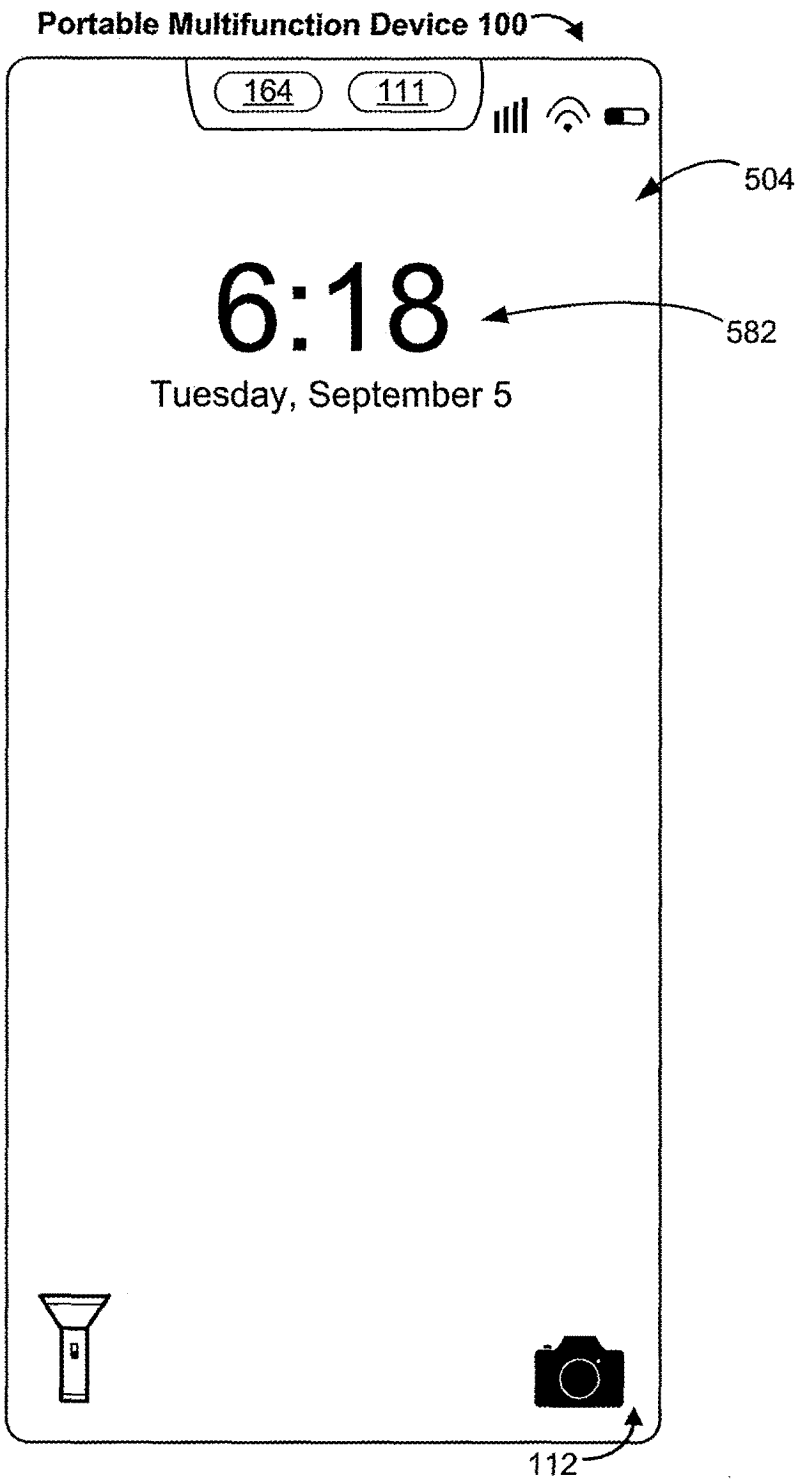


Figure 5CV

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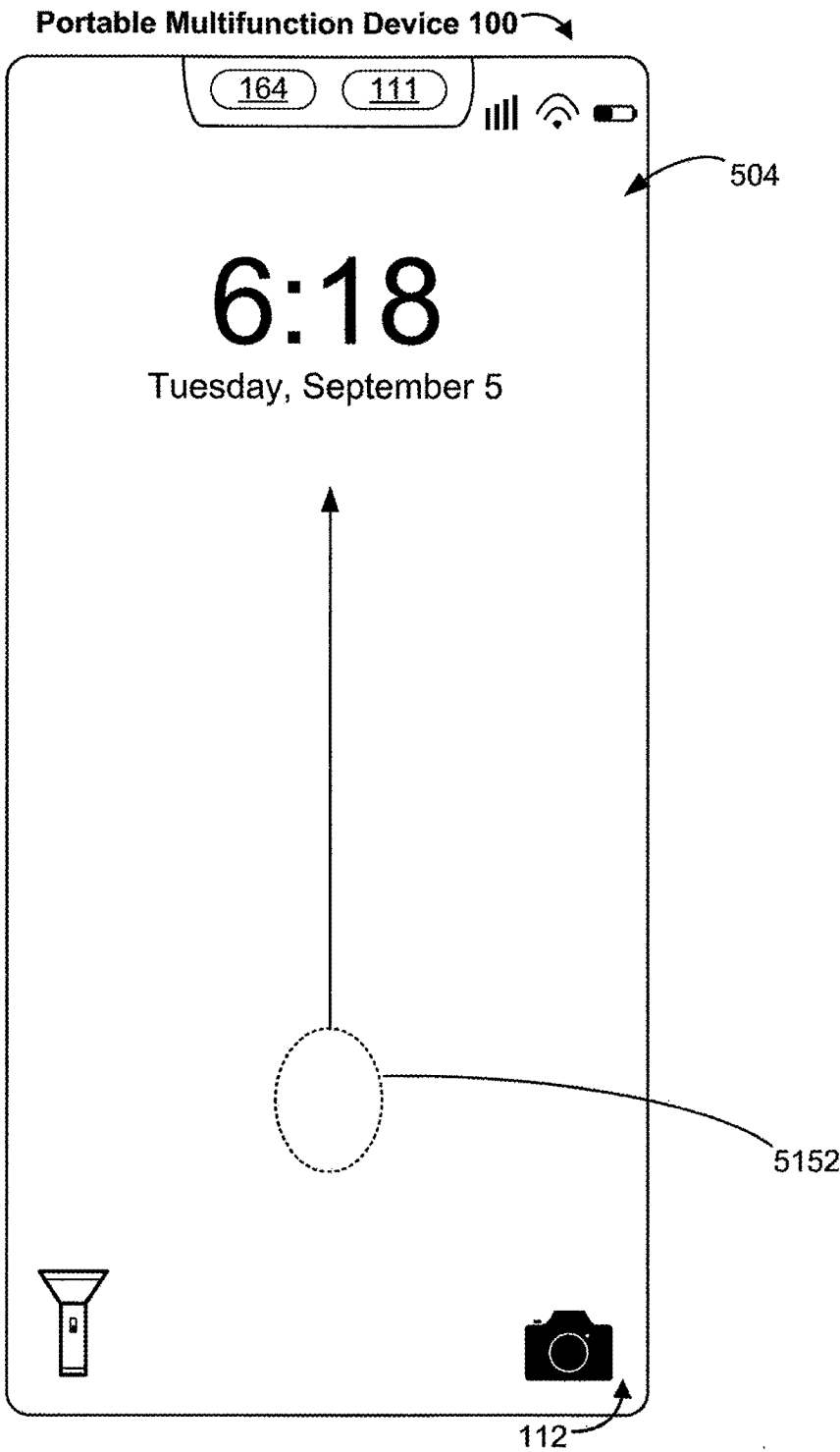


Figure 5CW

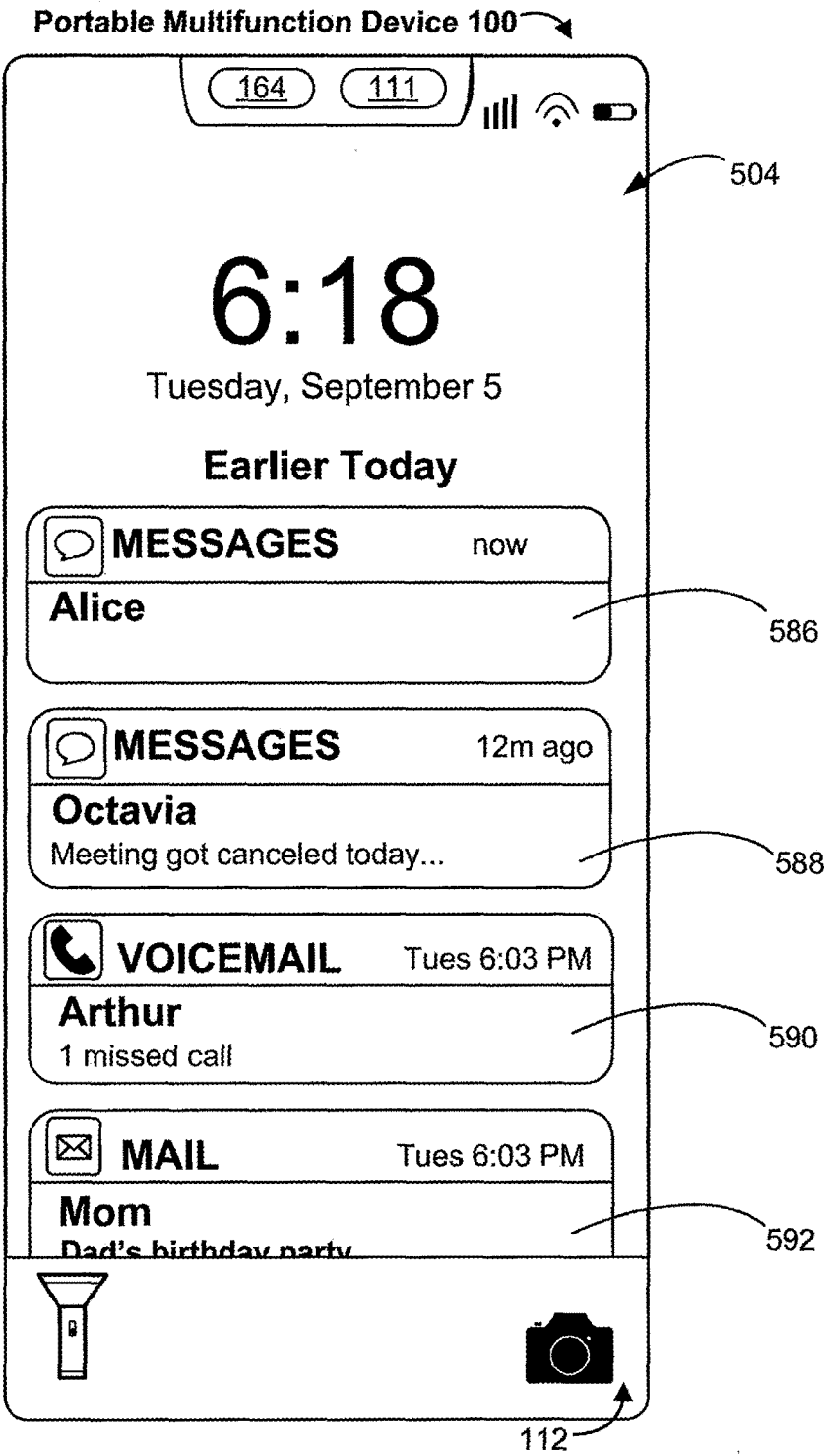


Figure 5CX

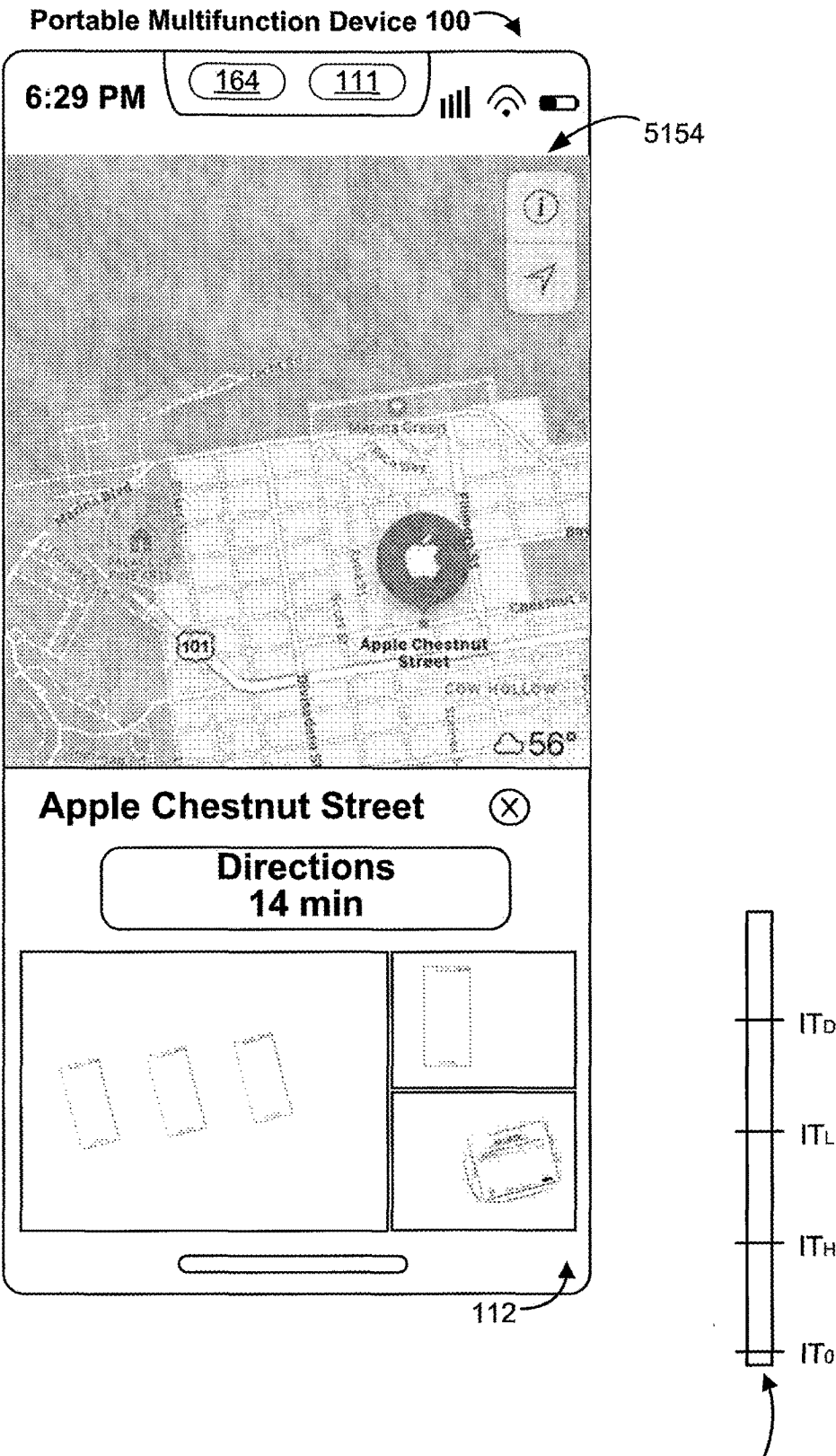


Figure 5CY